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DOCUMENTATION OF THE GUIDE TO GOOD PRACTICE FOR MINIMUM ODOR AND SMOKE FROM DIESEL-POWERED VEHICLES

Karl J. Springer, et al

Southwest Research Institute

Prepared for:

National Air Pollution Control Administration

November 1969

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SOUTHWEST RESEARCH INSTITUTE
Post Office Drawer 28510, 8500 Culebra Road
San Antonio, Texas 78228

DOCUMENTATION OF THE GUIDE TO GOOD PRACTICE FOR MINIMUM ODOR AND SMOKE FROM DIESEL-POWERED VEHICLES

by

Karl J. Springer
Allen C. Ludwig

FINAL REPORT

Prepared for

Emission Control Engineering Branch
Division of Motor Vehicle Pollution Control
National Air Pollution Control Administration
Contract No. CPA 22-69-71
U.S. Public Health Service
Department of Health, Education, and Welfare

November 1969

Approved:

John M. Clark Jr.

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Department of Automotive Research

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The report for air pollution abatement includes a

ABSTRACT

A "Guide to Good Practice for Minimum Odor and Smoke from Diesel-Powered Vehicles" ~~has been~~ prepared for use by interested government and private organizations, and individuals. This report contains documentation of the "Guide" in the form of literature references and personal interviews. Numerous figures and tables are interspersed, along with the citation of over 250 references to justify, document, and illustrate key points in the "Guide." Though not intended as a "critical review" of the literature, an attempt has been made to include the current state-of-technology consistent with field experience with commercial vehicles. Preference has been given to the more recent studies because of advances in the methods of smoke and odor measurement, as well as the use of current diesel engines and vehicles. Smoke control methods include engine derating (widely used), turbocharging (most effective during cruise), driver training (underspeeding, "lugging," and fuel injection adjustment may increase smoke), maintenance (engine breathing and fuel injection emphasized), and fuel additives (barium type most effective). For odor reduction, engine application, duty cycle, maintenance (engine breathing, fuel injection, and injector type, engine temperature) and driving habits (minimize idle in populated and closed areas of "lugging") were mentioned. The apparent minimal effect of fuels on odor and smoke is discussed, as well as odor additives. Location of the exhaust pipe (stack), as it affects the noticeability of odor and smoke, is stressed.

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I. INTRODUCTION

Prompted by numerous complaints from the public concerning smoke and odor emissions from diesel-powered vehicles, it was directed(1)* that a guide to good practice be prepared to assist the various government agencies to minimize smoke and odor. This Guide could also be helpful to those in the private sector associated with diesel-powered vehicles. While the total number of conventional diesel-powered vehicles within the government is relatively small (approximately 1600†)(2, 3), the number of people involved, such as drivers, mechanics, supervisors, and procurement specialists, is considerably larger. In addition, the total number of diesels in the country is constantly increasing to the point where it is anticipated that trucks will handle 25 percent of the ton-miles in the transportation of goods by 1980.(4) When these facts are considered in combination with the Federal regulations for smoke emissions(5, 6) from new engines and the probability of standards for exhaust odor in the future, a practical guide for reducing smoke and odor by all those who are involved with diesel-powered vehicles appears appropriate.

The draft of that guide, entitled "A Guide to Good Practice for Minimum Odor and Smoke from Diesel-Powered Vehicles," hereafter known as the "Guide," was submitted with this report. The purpose of this report is to bring together in one document the material and references used for the preparation of the "Guide" so that it may be fully documented. To reach the largest possible audience of truck drivers, sales and application engineers, procurement specialists, engine and vehicle maintenance technicians, fleet owners, and maintenance-driver supervisors, it was decided to prepare the "Guide" in as readable and as simple and direct a method as possible. Only one reference is cited in the "Guide," and that is to this final report. Accordingly, the organization of the "Guide," and, in some cases, the exact wording of sentences and paragraphs is repeated. Where necessary, such as the fuels and control techniques effects on smoke and odor, an analysis of the literature is offered. Additional comments to elaborate or introduce tabular or graphical data are also provided.

In gathering the information for the "Guide," the Library facilities at Southwest Research Institute were augmented with abstract literature searches in specific areas being conducted by:

---

*Superscript numbers in parentheses refer to list of references at the end of this report.

†This estimate does not include Department of Defense road and off-road combat vehicles.

(1) Southwest Research Institute personnel using APTIC's facilities

(2) API computer abstracting service

(3) Engineering societies library abstracting service

(4) Librarian consultant using the Naval library and other sources in Washington, D.C.

These abstracts were then reviewed and complete text obtained if warranted. Each library activity was coordinated to reduce the obvious overlap so that the "unfamiliar sources" were considered. To supplement the literature findings, personal interviews were conducted with Federal agencies currently using diesel-powered equipment, as well as engine/vehicle manufacturers, fleet operators, state pollution control agencies, enforcement personnel, and various transportation associations. These were most helpful in obtaining not only up-to-date findings but in acquiring experience in maintenance, driving, procurement, and related areas not widely covered in technical papers and journals or other library materials.

To fully document the "Guide," available references, interviews, and some unpublished data were utilized. Charts, data, and photographs are interspersed throughout this report to indicate the kind of information available and on which the "Guide" is based. In several instances, published data have been analyzed and presented in the form of bar charts or curves. It is quite possible to make different interpretations of some of the data than those elected in this report. In some cases, the data are inconclusive, contradictory, or obtained with obsolete or inconsistent means, or with laboratory single-cylinder or engines that are no longer commercially available. At the discretion of the authors, this information has been tempered by the field interviews and experience, and by more recent data using advanced or improved measurement techniques. Several gaps in the knowledge of diesel odor and smoke were identified as a consequence of this study and are so indicated.

II. GENERAL CHARACTERISTICS OF DIESEL ENGINES

It has been estimated(7) that each diesel-powered vehicle is viewed by 3-1/2 million Americans each year. This level of exposure tends to make people think that a diesel's contribution to air pollution is much greater than is really the case. This is further demonstrated by a recent national opinion survey which found that over 50 percent of those interviewed believed that diesel-powered vehicles were a major source of air pollution.(8) Of the estimated 100 million vehicles in this country(9, 10), diesels account for less than 1 percent of vehicle registration(10-16) and less than 5 percent of the fuel consumed by on-highway vehicles.(10, 11, 13, 16) Table 1(10) shows a recent breakdown of vehicles of all types contributing to air pollution. Since a diesel's exhaust may be noticed by so many people, complaints have resulted in legislation or proposed legislation to control diesel emissions.

The State of California has long been active in emissions control and currently limits the amount of smoke from industrial sources and vehicles(17) by using the Ringelmann Chart.(18, 19) California restrictions on smoke from diesels call for no more than a No. 1 Ringelmann for 10 sec from first sold or registered motor vehicles after January 1, 1971, operated at elevations less than 3000 ft. The current No. 2 Ringelmann would stay in effect for older vehicles operated at less than 3000 ft of elevation.(20) Emissions of carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x) are to be regulated by standards to be issued by January 1, 1971, to be met no later than January 1, 1973.(21)

All California Highway Patrolmen are supplied with a Ringelmann type smoke chart, shown in Figure 1, for enforcement purposes.(19) The state has conducted studies using a single-axle dynamometer installed at the Castaic Weigh Station(22) to measure smoke from diesel trucks and to evaluate smoke measuring procedures and equipment.(23, 24) Various views of a truck undergoing a typical test are shown in Figure 2. One of the smokemeters used was the U.S. PHS unit, shown in Figure 3, a full-flow, light-extinction meter which relates to what people see. Results indicated that a vast majority of the vehicles were clean, as shown in Figure 4.(25) California has also established a diesel odor standard(26, 27) calling for appraisal by a panel of not less than ten persons positioned near the tip of the exhaust pipe. Additional research and development of this method is anticipated before it will be enforced.

The State of New Jersey, armed with recent investigations of diesel smoke(28, 29), has proposed to enforce smoke standards using a free-acceleration test(30, 31) (the engine is accelerated from a high idle to governed rpm by flooring the accelerator pedal as rapidly as possible). Figure 5(29) shows the correlation between constant speed chassis dynamometer tests and the free acceleration tests. Enforcement on the road and at vehicle inspection

TABLE 1. POPULATION OF MOBILE SOURCES OF AIR POLLUTION IN USE IN THE UNITED STATES(10)

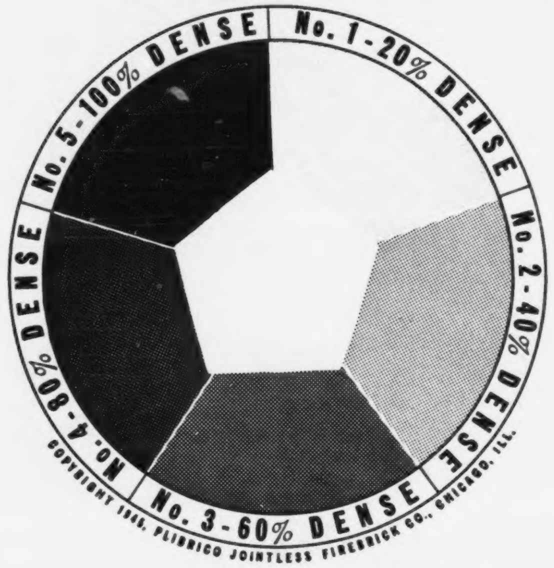
(As of 1968, except as noted)

Vehicle	Power Plant	Number in Use
Passenger Cars	Gasoline	83, 698, 100 (1968)
Trucks (Total)	Gasoline and Diesel	16, 998, 546 (1968)
Trucks	Diesel	416, 454 (1967)
Buses (Total)	Gasoline and Diesel	351, 804 (1968)
Buses	Diesel	65, 742 (1967)
Motorcycles	Gasoline	1, 753, 000 (1966)
Off-Highway Wheel Type Tractors (Contractors)	Gasoline and Diesel	21, 647*
Wheel Type Tractors (Except Contractors)	Gasoline and Diesel	2, 128, 914*
Tracklaying Tractors	Gasoline and Diesel	245, 595*
Aircraft (Non-Military)	Gas Turbine	2, 577 (1967)
Aircraft (Non-Military)	Piston Engine	151, 111 (1967)
Locomotives	Diesel	27, 045 (1968)
Ships	Diesel	Not Available
Outboard Motors	Gasoline	6, 988, 000 (1968)
Boats (Registered, pleasure)	Outboard	3, 965, 502 (1968)
Boats (Registered, pleasure)	Inboard	543, 216 (1968)
Utility	Gasoline	Not Available

---

*Total units manufactured 1959 through first 9 months of 1968.

CALIFORNIA HIGHWAY PATROL
SMOKE CHART
RINGELMANN TYPE


No. 1 - 20% DENSE
No. 2 - 40% DENSE
No. 3 - 60% DENSE
No. 4 - 80% DENSE
No. 5 - 100% DENSE
COPYRIGHT 1945, PLIBRICO JOINTLESS FIREBRICK CO., CHICAGO, ILL.

INSTRUCTIONS

1. The scale should be held at arm's length at which distance the dots in the scale will blend into uniform shades.

2. Then compare the smoke (as seen through the hole) with the chart, determining the shade in the chart most nearly corresponding to the shade or density of the smoke.

3. A motor vehicle shall be considered to be emitting "excessive" smoke, gas, oil or fuel residue if on visual comparison for a reasonable period the exhaust products have a density that is equal to or greater than No. 2 (40%) on the Ringelmann Chart.

Observer should not be less than 100 feet nor more than 500 feet from the vehicle.

Observer should avoid looking towards bright sunlight.

① △ OSP

FIGURE 1. RINGELMANN TYPE SMOKE CHART USED BY STATE OF CALIFORNIA

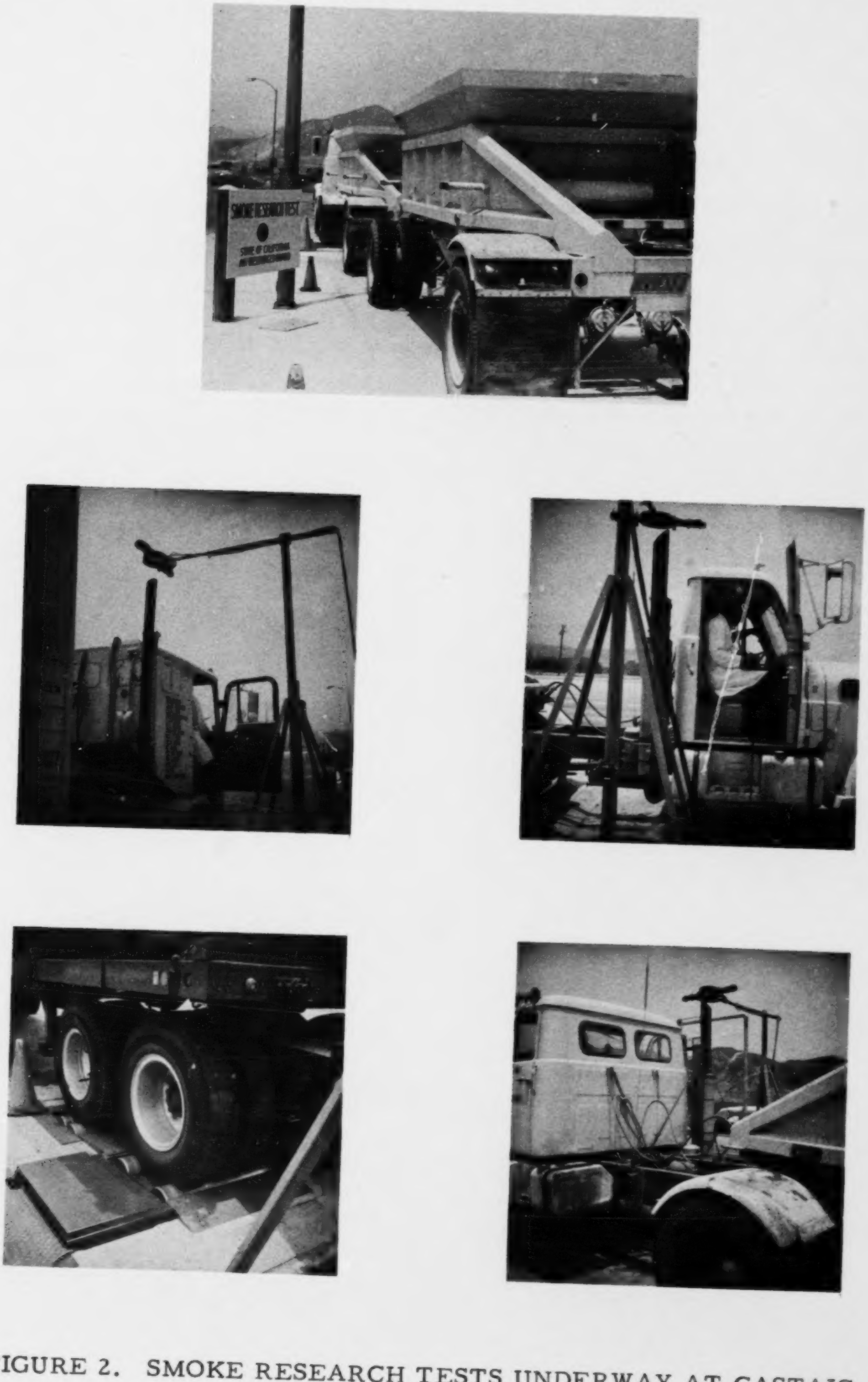

SMOKE RESEARCH TEST
STATE OF CALIFORNIA

FIGURE 2. SMOKE RESEARCH TESTS UNDERWAY AT CASTAIC BY STATE OF CALIFORNIA

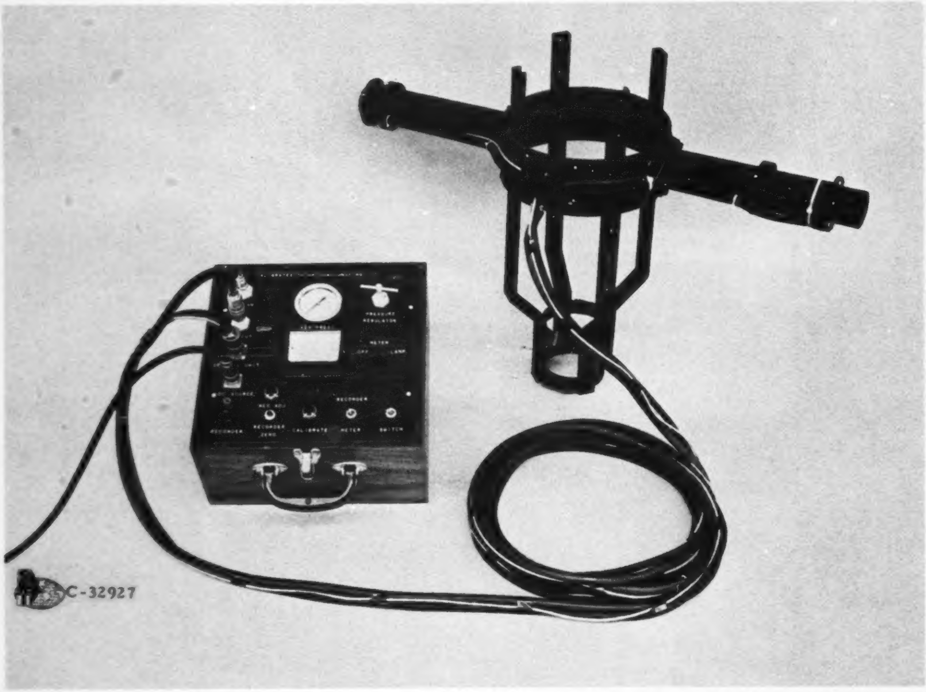


FIGURE 3. U. S. PHS DIESEL SMOKEMETER

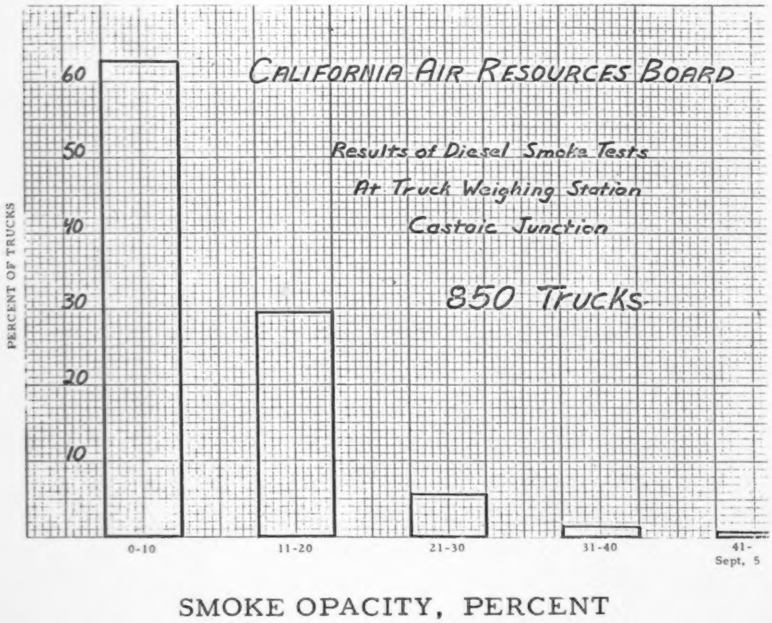


FIGURE 4. RESULTS OF DIESEL SMOKE TESTS - CASTAIC JUNCTION CONSTANT SPEED - MAXIMUM POWER

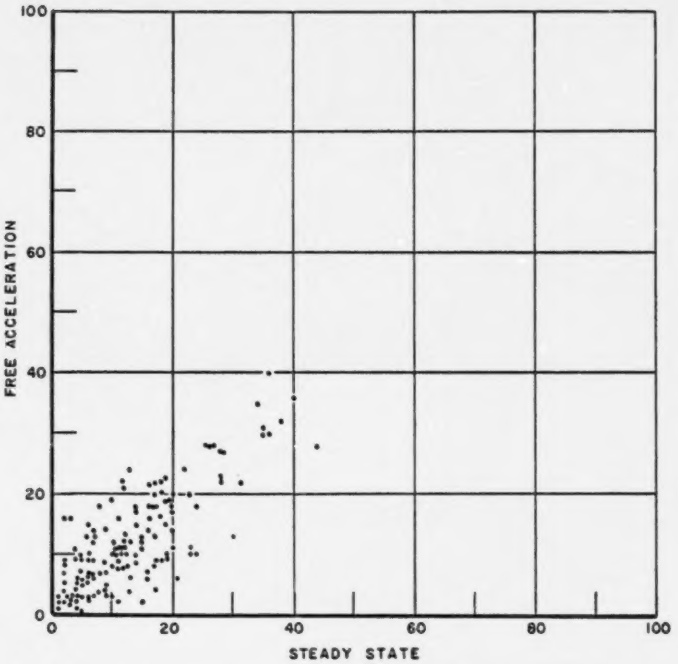


FIGURE 5. FREE ACCELERATION VERSUS STEADY-STATE SMOKE, BASELINE STUDY (PERCENT OPACITY)(29)

stations is anticipated no earlier than the Spring of 1970(3) and will depend on availability of a suitable, lightweight, compact, battery-powered, opacity type, full-flow smokemeter. Other states and municipalities including the cities of New York and Denver are in the midst of establishing emissions controls.(32-36) It is anticipated that other state and local governments will follow suit.

Although people may object to the smoke and odor emissions from the diesel, there is much confusion and misinformation concerning the health effect of these emissions. Air pollutants can be classed into three general categories: toxic, minor health hazards, and nuisances.(37, 38) Diesel odor and smoke are commonly considered by most health authorities to be of the nuisance type. There is a school-of-thought which considers the smoke particulate as a carrier capable of introducing, into the lung, condensed or other adsorbed contaminants which by themselves would not normally reach this portion of the body. Because little is known of this possible effect, these emissions continue to be considered of the nuisance type and, of themselves, to pose no significant health hazard.(39-58) The widespread use of diesels in confined areas such as mines, tunnels, and on board ships, both submarine and surface types, attests to the fact that diesel exhaust contains little in the way of hazardous materials and, compared to other power sources, is relatively efficient and clean.

The diesel-powered engine vehicle comes in many varieties ranging from mail delivery vehicles to line-haul tractors.(59-64) However, all "diesel" engines operate on the same principle. As the piston moves near the top of the cylinder on the compression stroke, the air charge is compressed to a high pressure and temperature. The fuel does not enter the cylinder as a mixture with air but is injected under high pressure into the chamber in precise quantities through carefully manufactured nozzles. Fuel injected into this high temperature air ignites without the aid of a spark. Ignition timing is controlled by timing the injection of the fuel.

Only the amount of fuel needed to produce a desired power output is injected. At idle, very little fuel is injected, while, at high speed and high power output, more fuel is needed. A convenient way to consider the diesel is the air-fuel ratio defined as:

$$\text{Air-fuel ratio} = \frac{\text{Amount of Air}}{\text{Amount of Fuel}}$$

in the cylinder available for combustion. A high air-fuel ratio (order of 100:1) exists during idle of the diesel.(65, 66) At full load conditions, the ratio is on the order of 20:1. Since this is greater than 15:1, the air-fuel ratio at which the correct amount of air and fuel is present for complete chemical combustion, the diesel may be considered to operate air-rich as shown in Figure 6.(67, 68) Because of this excess air, the diesel engine is inherently low in hydrocarbon and carbon monoxide emissions relative to a spark ignition engine.(65, 66, 69-78) The nitrogen oxide emissions, however, are similar for the two types of engines.(65, 67, 69, 72-77, 79-81)

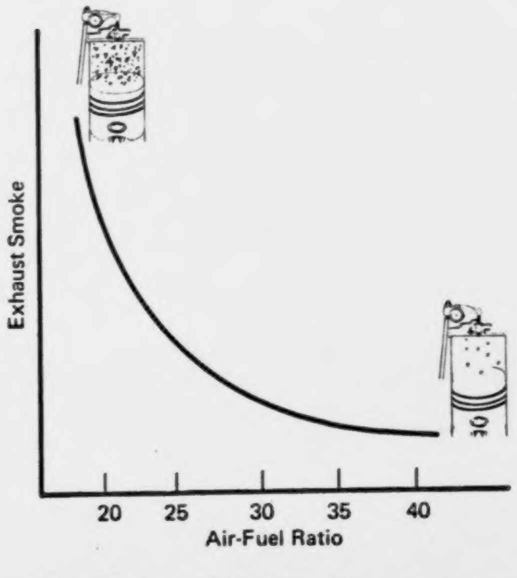


FIGURE 6. EFFECT OF AIR/FUEL RATIO ON SMOKE(67)

Both two-stroke (one power stroke per cylinder each engine revolution) and four-stroke (one power stroke per cylinder every two engine revolutions) engines are used and may be naturally aspirated (air is inducted from the atmosphere without external assistance) or turbocharged (exhaust energy is used to power a turbine air compressor to increase the amount of air per engine stroke). In most engines, except turbocharged, the amount of air handled is proportional to engine speed because there is no throttle in the inlet air system as there is in the gasoline engine. Fuel injection results in a largely heterogenous mixture, and ignition occurs spontaneously when the correct air-fuel and temperature conditions exist.

Numerous investigations have been concerned with alternate ways of injecting fuel into the cylinder.(82) Dr. Rudolph Diesel, the inventor of the diesel engine, used compressed air to inject the fuel into the cylinder. This system allowed premixing of the air and fuel, thereby resulting in smooth combustion. To eliminate the need for the bulky compressor, an injection pump was developed that injected the fuel directly into the cylinder. A precombustion chamber was found to improve the ignition lag characteristics of the direct injection system; with it, fuel is injected into a small precombustion chamber where part of the injected fuel is ignited. The fuel mixture is then directed into the main combustion chamber to give a smoother overall pressure rise. A more recent development has been the MAN ("M") system of combustion. With this system, fuel is injected onto the hot surface of a deep cupped piston head. Combustion is controlled by the evaporation rate of the fuel from the surface of the piston cup by a high-speed air swirl induced in the piston cup.

Although prechambers and a variety of piston configurations ("MAN," "Mexican Hat," etc.) have been developed, the simple open chamber with direct fuel injection remains the most popular in commercial over-the-road applications. For a more complete treatise on diesel engines and their design and operation, please refer to any basic textbook on internal combustion engines. Reference 10 contains a summary of the diesel, Otto spark-ignited, and Brayton cycle (gas turbine) which may be helpful.

In order to place the diesel in the proper perspective as an air pollution source, some background information on air pollution in general may be useful. The sources of air pollution can be described as either stationary sources, such as industrial and domestic, or moving sources, such as automobiles, trucks, boats, construction equipment, and aircraft. This is illustrated in Figure 7.(83) On a national average, the automobile accounts for approximately one-half of the emissions to the atmosphere.(36, 83-89) The diesel's contribution of the total air pollution from moving sources is relatively minor as illustrated in Figure 8. This chart was prepared from estimates given in References 10, 65, and 76. Typical emissions for a diesel and for both controlled and uncontrolled gasoline engines are listed in Table 2.(77) These figures were used as a partial basis for Figure 9, a bar

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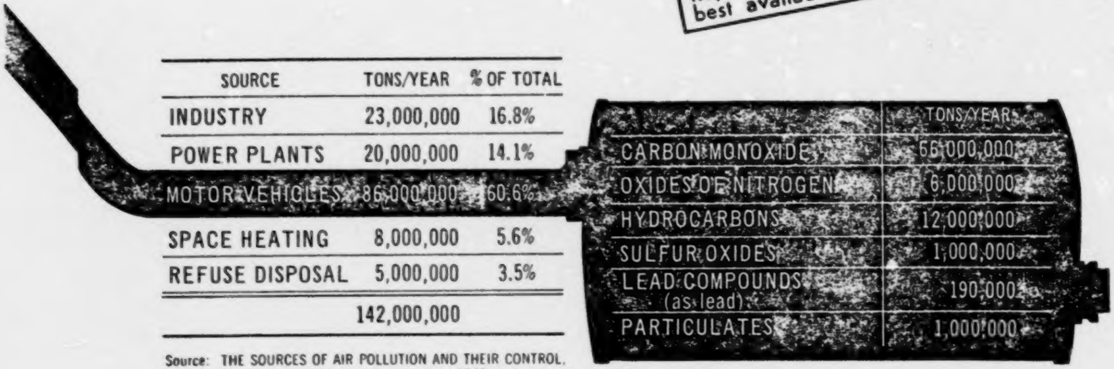


SOURCE	TONS/YEAR	% OF TOTAL
INDUSTRY	23,000,000	16.8%
POWER PLANTS	20,000,000	14.1%
MOTOR VEHICLES	86,000,000	60.6%
SPACE HEATING	8,000,000	5.6%
REFUSE DISPOSAL	5,000,000	3.5%
	142,000,000	

	TONS/YEAR
CARBON MONOXIDE	66,000,000
OXIDES OF NITROGEN	6,000,000
HYDROCARBONS	12,000,000
SULFUR OXIDES	1,000,000
LEAD COMPOUNDS (as lead)	190,000
PARTICULATES	1,000,000

Source: THE SOURCES OF AIR POLLUTION AND THEIR CONTROL. Department of Health, Education, and Welfare; 1966.

FIGURE 7. TOTAL U.S. AIR POLLUTION BY SOURCE--1966(83)

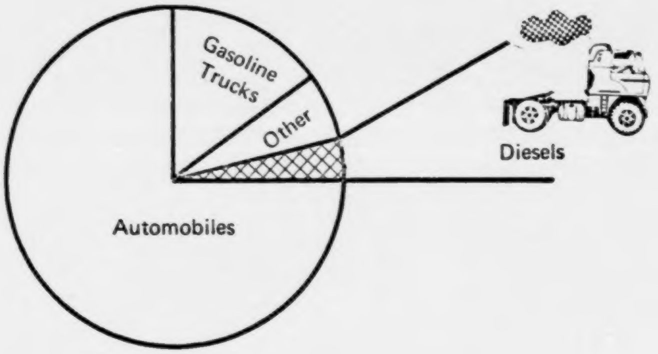


FIGURE 8. THE DIESELS' CONTRIBUTION

TABLE 2. COMPARISON OF VARIOUS VEHICULAR POWER PLANTS(77)

		EMISSIONS Grams/Mile California Driving Cycle			EMISSION INDEX	NOISE INDEX	FUEL CONSUMPTION Lbs/HP-Hr	RELATIVE WEIGHT	RELATIVE COST Morse Estimate	RELATIVE COST GM Estimate
		HC	CO	NO						
GASOLINE ENGINE 1960		11.0	80	4	HIGH	MEDIUM	.45	1	1	1
GASOLINE ENGINE	1970	2.2	23	4?	LOW	MEDIUM	.50	1—1.5	---	1—1.5
	197X	STILL LOWER								
DIESEL		3.5	5	4	MEDIUM	HIGH	.40	2.5	1.85	2—2.5
REGENERATIVE GAS TURBINE		0.22	2.4	1.0	LOW	MEDIUM	.45	2	3.75	3
STIRLING		0.1	1.0	2.6	LOW	LOW	.40	2.5	2.5	3
STEAM		0.62	2.8	1.0	LOW	LOW	.70+	3.0	1.5	3
ELECTRIC BATTERY AND MOTOR		---	---	---	LOW	LOW	?	4?	---	6?

PROPOSED 1970 FEDERAL STANDARDS: Hydrocarbons: 2.2 Grams per Mile
Carbon Monoxide: 23 Grams per Mile

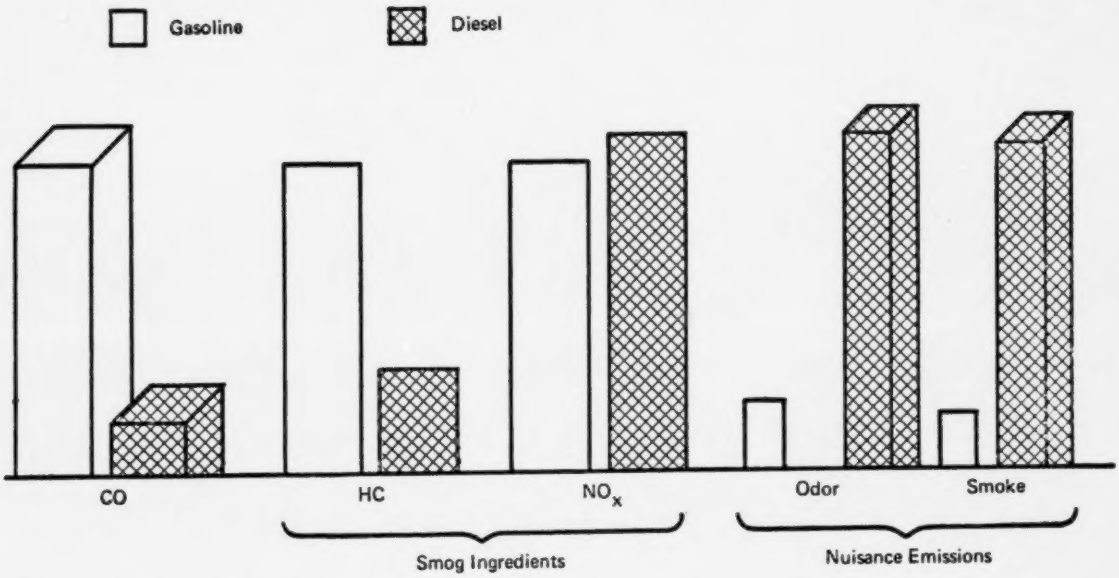


FIGURE 9. COMPARISON OF EMISSIONS FOR THE DIESEL AND GASOLINE ENGINE

chart which compares the specific emissions from a gasoline and a diesel engine in relative terms. It is not commonly known that the diesel emits far less toxic CO and smog-forming hydrocarbons than the gasoline engine. When the diesel is operated with an air-fuel ratio less than about 25:1, visible smoke may occur. For some engines, the sum of the smoke, CO, and HC is nearly constant regardless of air-fuel ratio. On the otherhand, the variations in air-fuel ratio within the usual range of operation appear to affect odor only slightly in some engines and not at all in others.

A. Types and Causes of Smoke and Odor

1. Types of Smoke

There are three generally recognized types of smoke.(65, 90, 91)

(1) White or Cold Smoke--Unburned droplets of liquid fuel usually associated with start-up or idle for some engines.

(2) Blue Smoke--Unburned engine oil which reaches the combustion chamber because of worn piston rings, cylinder liners, and/or valve guides, and may include partially burned fuel.

(3) Dark, Black or Hot Smoke--Unburned carbon particles (soot) usually associated with engines at operating speeds, loads, and temperatures.

The first type of smoke can be reduced by minimizing idle time, especially after initial start-up, and using fuel with ignition properties suitable for the climate. Indoor parking and engine block heaters will also reduce cold smoke. Engine maintenance or overhaul can generally eliminate the occurrence of blue smoke. The dark gray or black smoke is the most common type and is the principal smoke type discussed in the "Guide." Dark Smoke is always related to incomplete combustion.

2. Causes of Smoke

Smoke is generally the result of incomplete combustion brought about by a number of engine operating conditions as presented in Figure 10.(90) The smoke tendencies of diesel engines can vary greatly depending on the engine type--either naturally aspirated or turbocharged.

Turbocharged engines produce less smoke at cruise because the air-fuel ratio can be higher for the same power than that for the naturally aspirated engine. Based on recent studies(92, 93), typical values for naturally aspirated four-stroke engines may vary from 10- to 30-percent opacity under

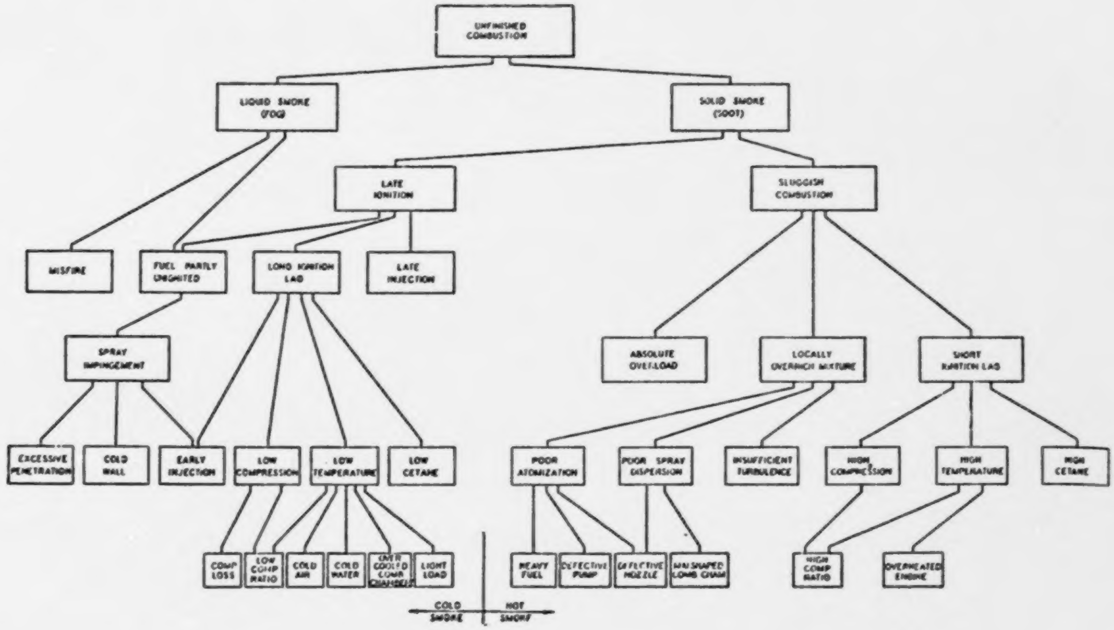
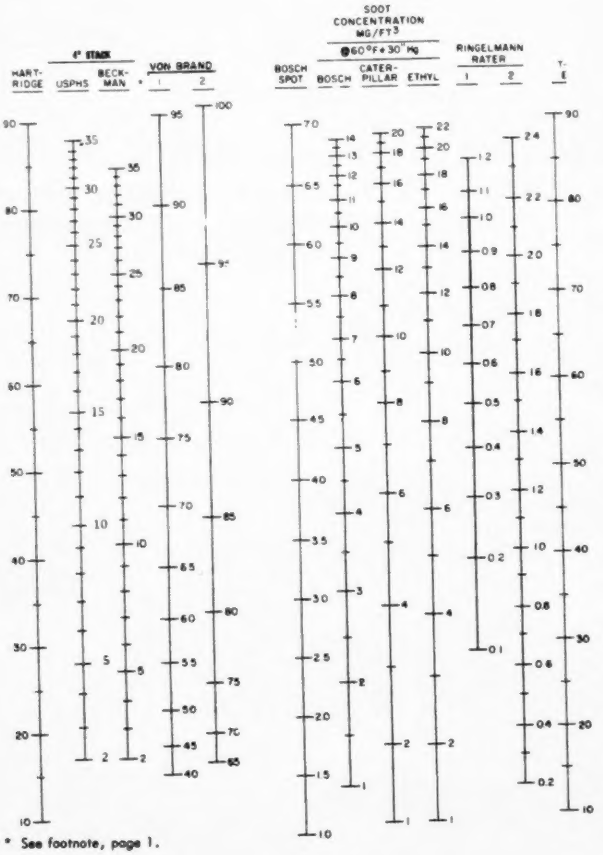

UNFINISHED COMBUSTION
LIQUID SMOKE (FOG)
SOLID SMOKE (SOOT)
LATE IGNITION
SLUGGISH COMBUSTION
MISFIRE
FUEL PARTLY UNIGNITED
LONG IGNITION LAG
LATE INJECTION
SPRAY IMPINGEMENT
ABSOLUTE OVERLOAD
LOCALLY OVERRICH MIXTURE
SHORT IGNITION LAG
EXCESSIVE PENETRATION
COLD WALL
EARLY INJECTION
LOW COMPRESSION
LOW TEMPERATURE
LOW CETANE
POOR ATOMIZATION
POOR SPRAY DISPERSION
INSUFFICIENT TURBULENCE
HIGH COMPRESSION
HIGH TEMPERATURE
HIGH CETANE
COMP LOSS
LOW COMP RATIO
COLD AIR
COLD WATER
OVER COOLED COMB CHAMBER
LIGHT LOAD
HEAVY FUEL
DEFECTIVE PUMP
DEFECTIVE NOZZLE
MIS SHAPED COMB CHAM
HIGH COMP RATIO
OVERHEATED ENGINE
COLD SMOKE
HOT SMOKE

FIGURE 10. CAUSES OF COLD AND HOT SMOKE FROM THE DIESEL ENGINE(90)

both cruise and transient acceleration from idle. The turbocharged engines studied (with some exceptions) exhibited 5- to 10-percent opacity under cruise and 25- to 65-percent peak opacity readings during acceleration from idle. The high compression N type two-stroke engine produced a lower level of smoke, generally on the order of 5 to 10 percent at cruise and less than 20 percent during acceleration from idle.(92-94)

The previous discussion, in terms of the opacity readings via the PHS full-flow meter, may be converted to other types of meter readings by means of correlation data given in References 92 and 95 to 106. Of these, the CRC and SAE correlation studies(101-105) are an attempt to relate the PHS to other meters such as the B. P. Hartridge, widely used in Europe, and the Bosch spot meter and Von Brand filter tape, two sampling meters widely used in this country, among others. A helpful nomograph is shown as Figure 11.(105)



* See footnote, page 1.

FIGURE 11. NOMOGRAPH RELATING VARIOUS DIESEL SMOKEMETERS(105)

B. Odor Characteristics

A number of research investigations have been conducted or are currently in progress(65,92,95,107-118) to learn more about diesel odor, its causes, its components, and its cure. Identification of specific odorants has been difficult, as have many attempts to define its cause and prescribe its remedy. Simply defining diesel odor is a hard task, and, currently, panels of trained observers are used to judge odor quality and intensity against a series of odor standards.(119-123) A wide variety of other odor measurement methods has been employed using single as well as jury type responses under a variety of scales. This variety is indicated in Figure 12.(94, 124)

A method developed by Dr. Amos Turk for the U. S. Public Health Service, known as the Quality/Intensity (Q/I) kit (Figure 13)(92) is used by some investigators as a standard against which diluted diesel odor is rated and expressed. To utilize this kit, a trained panel of observers is required as well as special facilities. A typical odor panel is shown in Figure 14.(95) It appears that the human element will be relied on until an instrumentation method has been developed and correlated.

One such panel(92, 95) has described the odor from municipal buses as a burnt, smoky kerosene or sometimes as a sweet aromatic smell. The same panel characterizes the odor from a popular four-stroke diesel-powered over-the-road tractor as containing little fuel or aromatic odor with a more penetrating, musty, pungent odor similar to that from coal smoke. The causes of odor, while generally attributed to partially burned fuel compounds, cannot be related to any specific engine characteristic or operating conditions as readily as are smoke emissions.(65, 92, 115) Odor may or may not be associated with smoke emissions, as noticeable odor levels can occur even though there is no visible smoke such as at idle.(92, 95, 115)

While the location of the exhaust pipe does not affect the production of malodorous exhaust, it can affect the level of atmospheric dilution and consequent noticeability. Therefore, stack or pipe location and direction are important vehicle design criteria. A recent study(95) using trace gas introduced into the exhaust of a vertical stack-equipped truck-tractor, Figure 15, and a horizontal exhaust pipe municipal bus, Figure 16, revealed that typical dilutions from the vertical stack were seven times those of the horizontal pipe (range of 700:1 to 7000:1 for vertical and a range of 100:1 to 1000:1 for horizontal exhausts). This would indicate that odor intensities could be reduced by using vertical stacks. Some fleets, however, particularly those engaged in frequent stop-and-go in public or downtown areas, create more complaints in the long run because of the possible fallout of soot on both people and property.(3) Extensive idle periods sometimes result in moisture condensation, and a mixture of soot and water has been shown to be more troublesome from vertical rather than from horizontal exhaust. Fleet operators' experiences with well-maintained low smoke vehicles indicate that, if the public does not see the smoke, they have less tendency to complain about the odor, even though both still occur.

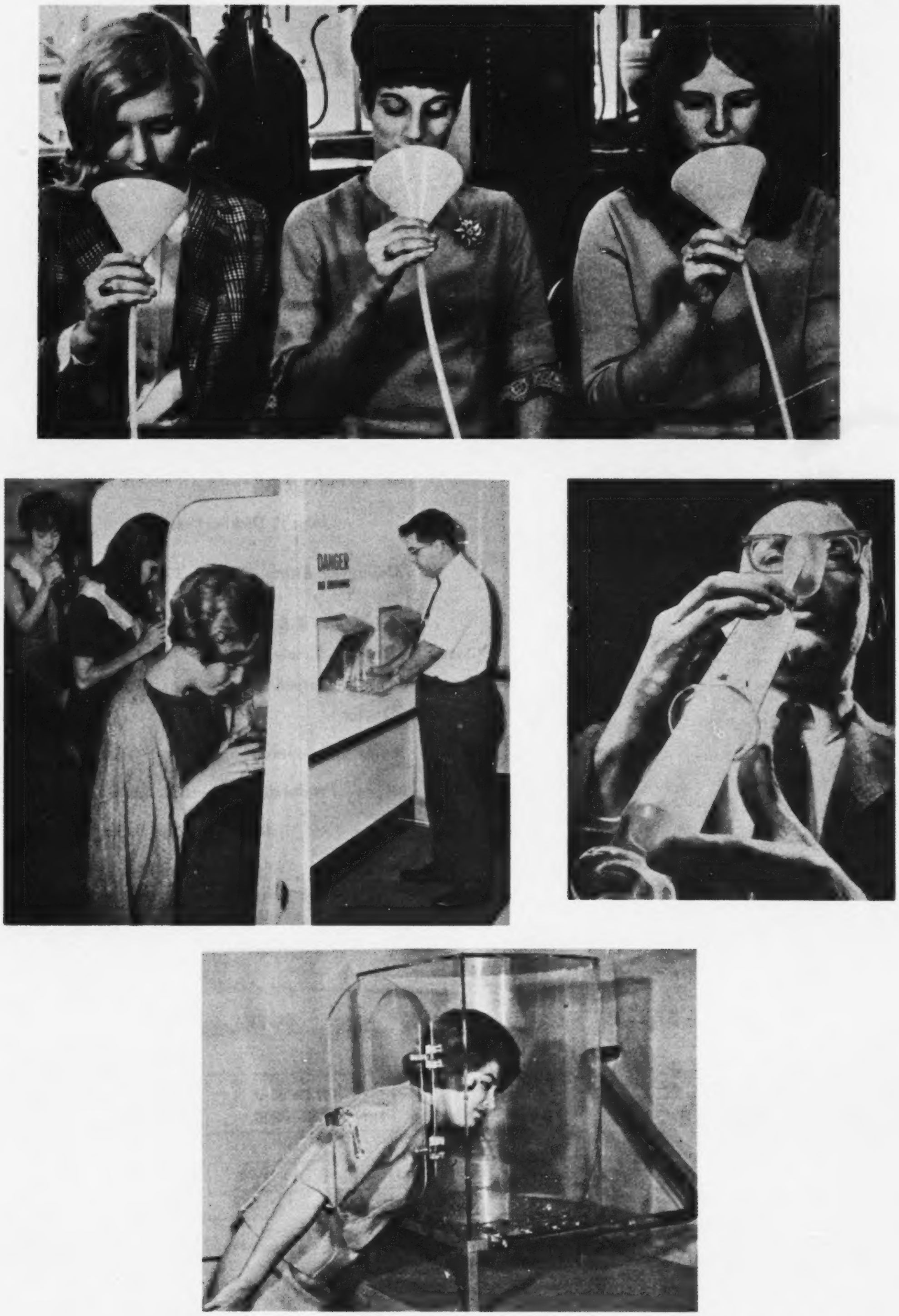


FIGURE 12. TYPICAL ODOR PANELS FOR EVALUATING DIESEL EXHAUST ODOR(94, 124)

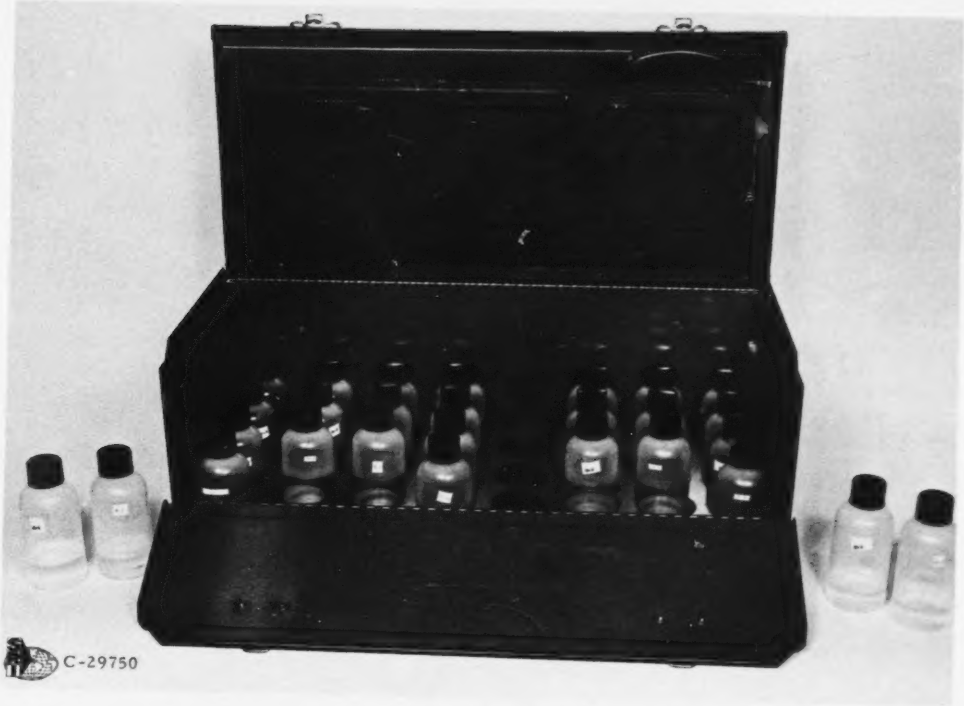


FIGURE 13. U. S. PHS QUALITY/INTENSITY KIT FOR RATING DILUTE DIESEL ODOR(92)

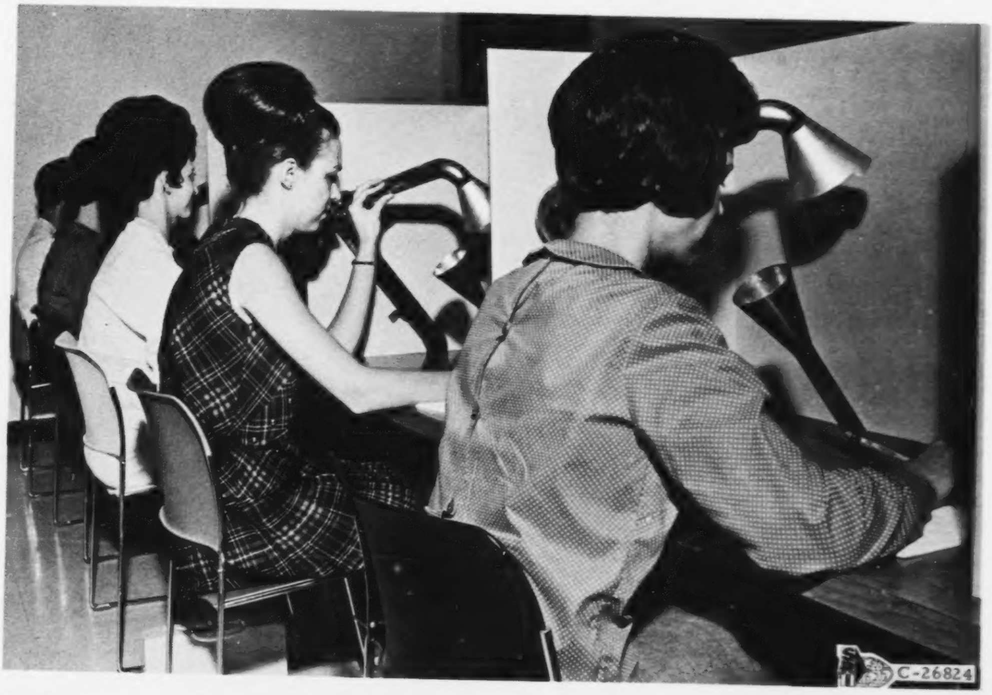


FIGURE 14. TRAINED PANEL FOR EVALUATION OF DILUTE DIESEL ODOR USING PHS QUALITY/INTENSITY KIT(95)

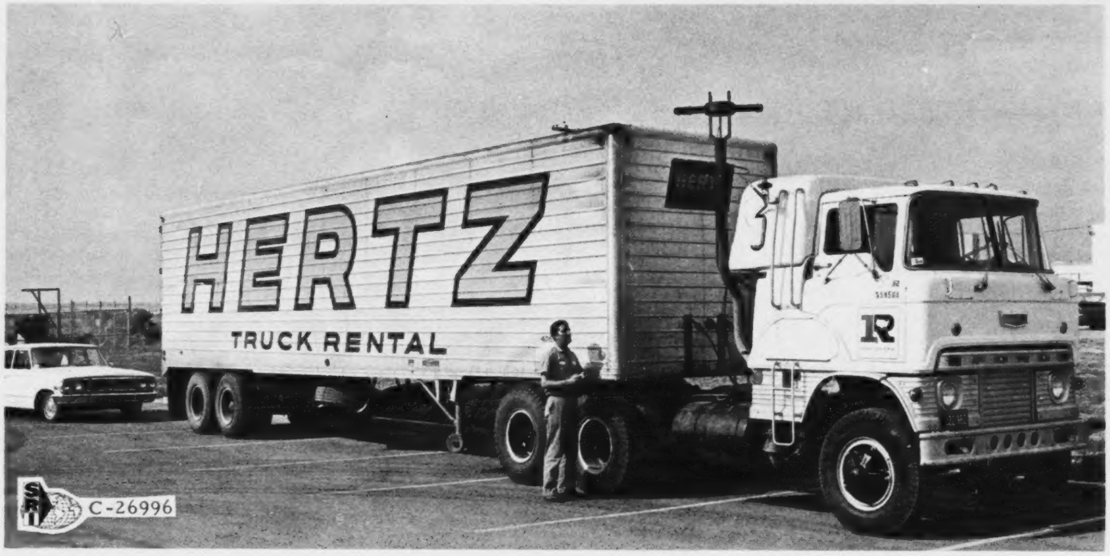

HERTZ
TRUCK RENTAL
C-26996

FIGURE 15. EXHAUST DILUTION STUDY OF VERTICAL STACK EQUIPPED TRACTOR-TRAILER TRUCK(95)

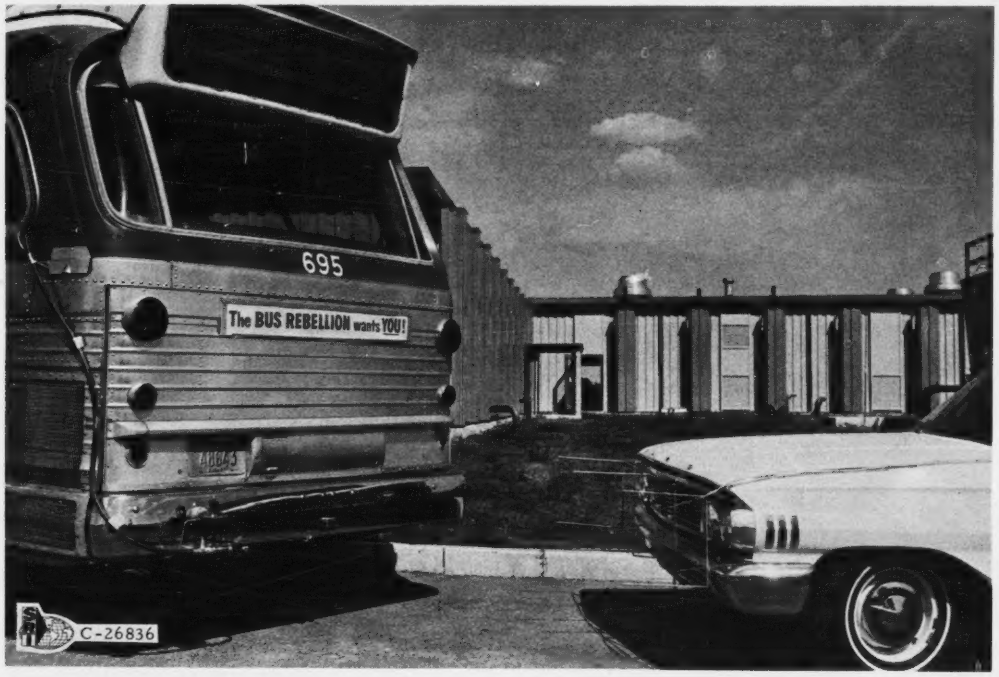

695
The BUS REBELLION wants YOU!
C-26836

FIGURE 16. EXHAUST DILUTION STUDY OF HORIZONTAL PIPE EQUIPPED MUNICIPAL BUS(95)

III. GUIDELINES FOR MINIMUM SMOKE

Following the outline of the "Guide," justification of the guidelines for minimum smoke are presented under categories of engine application, derating, maintenance, driver effects, fuel, and control methods.

A. Effect of Engine Size and Application on Smoke

The selection of a diesel engine for a truck or bus is made to give maximum power at the rear wheels in the most dependable, safe, and economical way possible.(125, 126) This involves more than the engine itself; it encompasses the entire driveline, including the transmission and rear axle. Because of the wide variety of applications, duty cycles, and terrain encountered in the United States, engine selection is often more an art than a science.

Engine and vehicle manufacturers have excellent application guides for this purpose, as typified by Reference 127. In addition, the Society of Automotive Engineers (SAE) published a "Truckability Prediction Procedure J688"(128) (currently being revised) that has been used to select engines and drivelines for specific applications. The sad fact is that the manufacturers' application recommendations are often used only as a rough approximation, especially in competitive bids. In order to save $100 to $500 on a vehicle costing $20, 000 to $30, 000, it is not unusual to select or propose a smaller engine. This type of selection, on the basis of original or capital equipment cost, can be false economy. Most commercial vehicle operations require and use all the power available, whereas only a fraction of the available power is utilized much of the time in passenger automobiles. When engine deterioration begins to occur or if the maximum legal weight increases, as is currently pending(129, 130), more power is needed. Sometimes the need for more power from a marginal or undersized engine results in overfueling which, in turn, causes excessive smoke.

The rating of a diesel engine usually is a compromise between smoke, efficiency, power to weight and displacement, and other factors. A review shows that past practice has been to select a smoke level which seemed acceptable, and then fuel at that rate. The advent of smoke test regulations for 1970 calendar year diesel production will set a maximum limit on what level of smoke will be acceptable under the cruise or "lug-down" (20-percent opacity--PHS) and transient acceleration (40-percent opacity--PHS). This will have some effect on engine ratings since the manufacturer has an upper smoke limit to meet and since partial standardization will result.(58)

The relationship between smoke and power is by no means common or one shared by all engines types and models. To prepare the trend curve shown in the "Guide" as Figure 6, smoke data from a number of naturally aspirated and turbocharged engines were considered. Though some were flat and others were steep linear curves, many exhibited an increased rate of smoke as power increased. Typical results for a widely used, direct-injected four-stroke engine powering a single-drive axle tractor are shown in Figure 17 (from unpublished SwRI data). Other experiments have shown twice the smoke by merely increasing the engine power output from 200 to 210 hp.(92, 95) A few engines, on the other hand, must be grossly overfueled before a substantial smoke increase is noted(92), but this is the exception to the rule. Another consideration is that if an engine is marginal or too small, it will exceed the rated engine output a greater percentage of the time. This will result in more smoke for certain types of engines and may eventually cause mechanical damage.

The selection and application of engines for vehicles which must operate at varying elevations or altitudes are also important from a smoke standpoint. Smoke is related to the air-fuel ratio, and anything which tends to change this ratio can have an influence on smoke. Since the air density decreases with an increase in altitude, according to Table 3, the air-fuel ratio will change as altitude increases. Likewise, the inlet air temperature can affect the air density, as per Table 4. One manufacturer(131) recommends

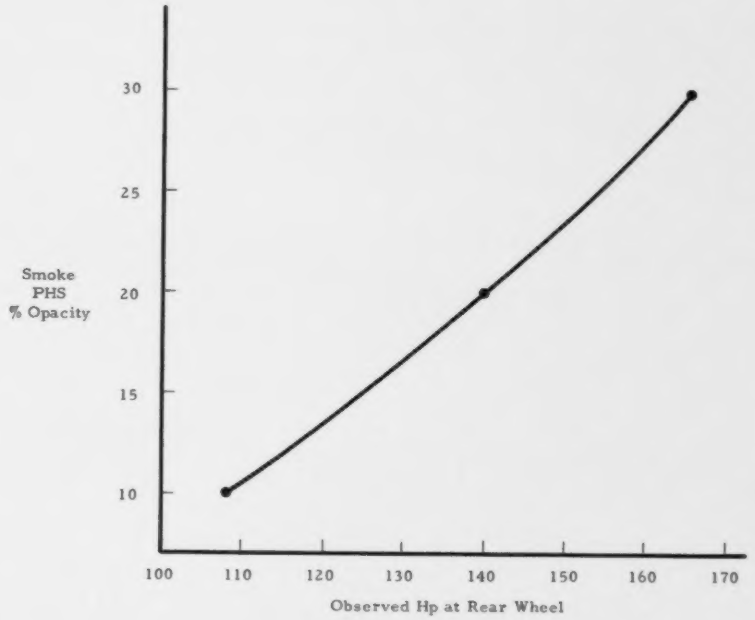


FIGURE 17. EFFECT OF POWER ON SMOKE FROM A POPULAR FOUR-CYCLE DIESEL-POWERED TRUCK AT CONSTANT SPEED

(Unpublished SwRI data)

TABLE 3. EFFECT OF ELEVATION ABOVE SEA LEVEL ON INLET AIR DENSITY

Altitude Above Sea Level, ft	0°F	Inlet Air Density, lb/cu ft 32°F	60°F	120°F
0	0.086	0.081	0.076	0.068
1,000	0.083	0.077	0.074	0.066
2,000	0.080	0.074	0.071	0.064
3,000	0.077	0.072	0.069	0.062
4,000	0.074	0.070	0.067	0.061
5,000	0.072	0.068	0.065	0.059
6,000	0.069	0.066	0.063	0.057
7,000	0.067	0.064	0.061	0.056
8,000	0.065	0.062	0.059	0.054
9,000	0.063	0.060	0.058	0.053
10,000	0.061	0.058	0.056	0.052

Above based on local gravity equal to standard gravity.

TABLE 4. EFFECT OF AIR TEMPERATURE ON INLET AIR DENSITY

Inlet Air Temperature, °F	Inlet Air Density lb/cu ft 1000 ft	3000 ft	5000 ft	10,000 ft
-30	0.088	0.082	0.076	0.064
0	0.083	0.077	0.072	0.061
32	0.078	0.072	0.068	0.058
60	0.074	0.069	0.065	0.056
90	0.070	0.065	0.062	0.054
120	0.066	0.062	0.059	0.052
150	0.063	0.060	0.056	0.050

Above based on local gravity equal to standard gravity.

a 3-percent derating per 1000-ft elevation rise and a 1-percent derating in engine power per each 10°F air temperature rise above 60°F for its line of naturally aspirated engines. Because of the excess air delivered to the engine at sea level and the self-compensating effect of the turbocharger at high altitudes, most turbocharged diesels can be operated up to 6000 to 8000 ft with little or no derating.

Although a sizable portion of the land area of the Continental U. S. is at an elevation greater than 3000 ft above sea level, very little data and few published reports are available documenting this effect on smoke relative to sea level. Truckers, automotive engineers, drivers, and others closely related to the diesel in over-the-road operations have long known that practically all diesel engines smoke more at altitude. To illustrate the effect, Figure 18 was included in the "Guide" (Figure 7) as a trend curve. The curve shows the general effect of altitude on both turbocharged and naturally aspirated engines. In the case of turbocharged engines, smoke was increased slightly in an almost linear way. This is in general agreement with Figure 19(132) and is considered fairly reliable.

Similar curves for commercially used, naturally aspirated diesel engines have not been located in the open literature. Through a number of conferences with diesel emissions experts(3), trend curves for the naturally aspirated engine were drawn and represent the fuel-air versus smoke inset curve in Figure 18. Thus, a naturally aspirated engine which has very little smoke at sea level may be expected to produce more smoke at 5000 ft, while that same engine, if producing about 20-percent opacity at near sea level, may produce as much as 40 percent (twice as much) at 5000 ft. Using these estimates, an engine which just meets the Federal Smoke Requirements for 1970 (sea level tests are permitted) of 20-percent opacity (constant speed) may produce substantially more smoke if operated at 5000 ft.

To validate and demonstrate this effect, Southwest Research Institute, under the joint sponsorship of the Automobile Manufacturers Association and Engine Manufacturers Association, has operated a popularly used, N/A four-stroke diesel tractor tank-trailer at San Antonio, Texas, elevation 820 ft; Amarillo, Texas, elevation 3600 ft; and Denver, Colorado, elevation 5280 ft and obtained smoke and engine performance at a variety of engine fuel rates and speeds. The effect of altitude on smoke is an additional factor which must be considered by Federal, state, and local governments; control agencies; and enforcement officials in controlling smoke from diesel-powered vehicles.

Thus, it would appear that naturally aspirated and turbocharged engines having low smoke tendencies would be the best selection for operation at higher altitudes. It should be remembered, however, that the turbocharged engine has a greater smoke tendency during acceleration conditions. This means the type of vehicle and service intended will have an effect and should

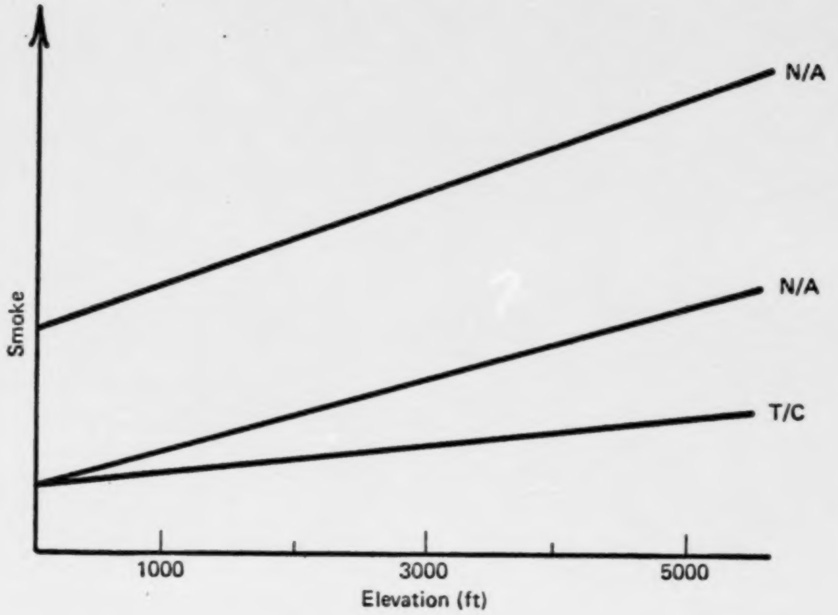


FIGURE 18. EFFECT OF ELEVATION (ALTITUDE) ON SMOKE

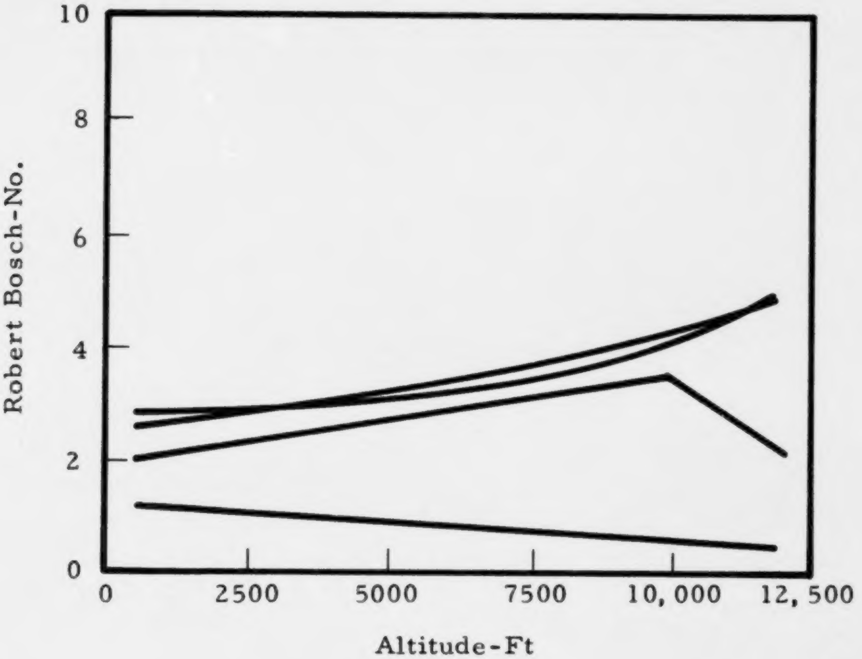


FIGURE 19. SMOKE FROM GENERAL MILITARY TURBOCHARGED DIESEL ENGINES(132)

be considered. If a vehicle is operated at higher altitudes consistently and is engaged in stop-and-go service, a low smoke tendency, naturally aspirated engine may contribute less overall smoke, particularly if adjusted for altitude conditions.(3) On the other hand, if a vehicle is to operate under cruise type conditions, the turbocharged engine would tend to produce lower smoke at higher altitudes. With the trend toward the "high torque rise" type of engine and fewer forward gears, operation of both types of engines, particularly the turbocharged, under stop-and-go service at altitude, may cause the engine to labor excessively and result in more smoke.(3)

B. Engine Derating Can Help to Minimize Smoke

Engine derating is one of the most popular and widely used methods for the reduction of visible smoke. Engine derating means reducing the available power or rating of an engine and is normally accomplished by reducing the amount of fuel injected per stroke throughout the operating speed range of the engine. A change to smaller injectors, reduced fuel delivery pressure, or fuel pump calibration can effect a substantial reduction in the smoke discharge as illustrated in Figure 20. While smoke reductions are a very positive result of engine derating, several other advantages are improved fuel economy, extended engine life with less maintenance and breakdowns, plus the capability of up-rating the engine at a later date should legal weight limits increase.(3, 92, 93, 95, 133, 134)

The effect of speed on smoke was shown in Figure 8 of the "Guide" for two-stroke and some four-stroke engines (Bosch type injectors) and for four-stroke engines using the Cummins PT type system. These trend curves were based on typical curves in the literature and actual dynamometer and field smoke measurement experience.(29, 92, 95, 115, 135, 136, etc.) Many four-stroke engines employing the Bosch injection equipment produce more smoke as the speed decreases, commonly referred to as "lug-down." Curves for typical in-service tractors powered by N/A or T/C engines follow the general trend shown in Figure 21. The general smoke characteristic of the N/A, two-stroke engines with speed is shown in Figure 22 and, according to Reference 136, may be attributed to the compressibility of the fuel and leakage past the injector plunger due to increased fuel injection pressure. The unit injector fuel delivery characteristics versus speed are shown in Figures 23 and 24.(136)

Some four-stroke engines employ the Cummins PT type fuel system in which the reverse characteristic (i.e., an increase in smoke with an increase in speed) occurs. Smoke from a typical in-service tractor is plotted against speed at maximum power in Figure 25.(92, 95, 115) Schweitzer(90) discusses this general characteristic and attributes it to decreased air charge because of volumetric efficiency while the fuel delivery remains constant or increases. In effect, the air-fuel ratio decreases with an increase in speed under maximum output conditions. Some operators

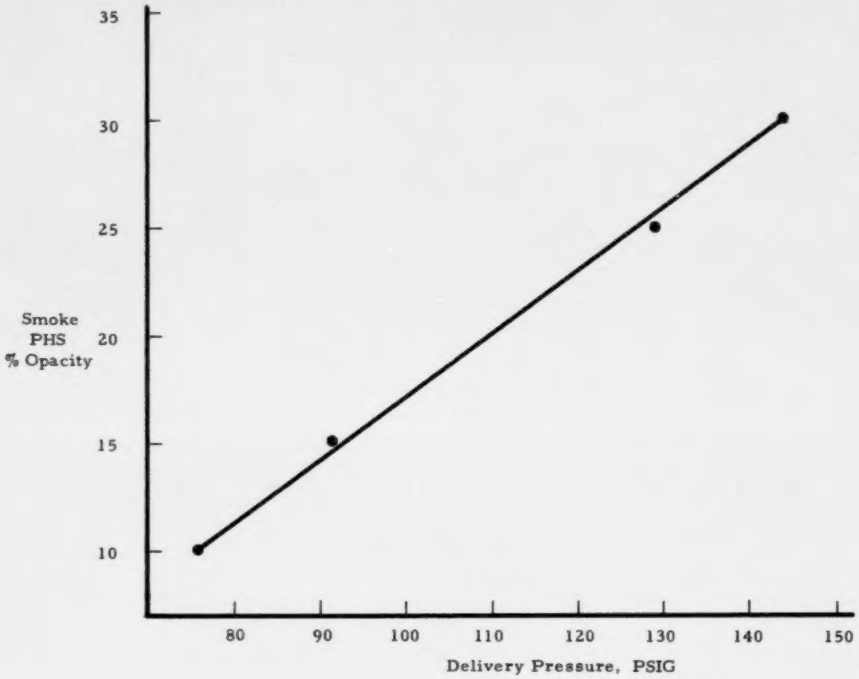


FIGURE 20. EFFECT OF FUEL DELIVERY PRESSURE ON SMOKE AT CONSTANT SPEED FROM A POPULAR FOUR-STROKE DIESEL ENGINE (UNPUBLISHED SwRI DATA)

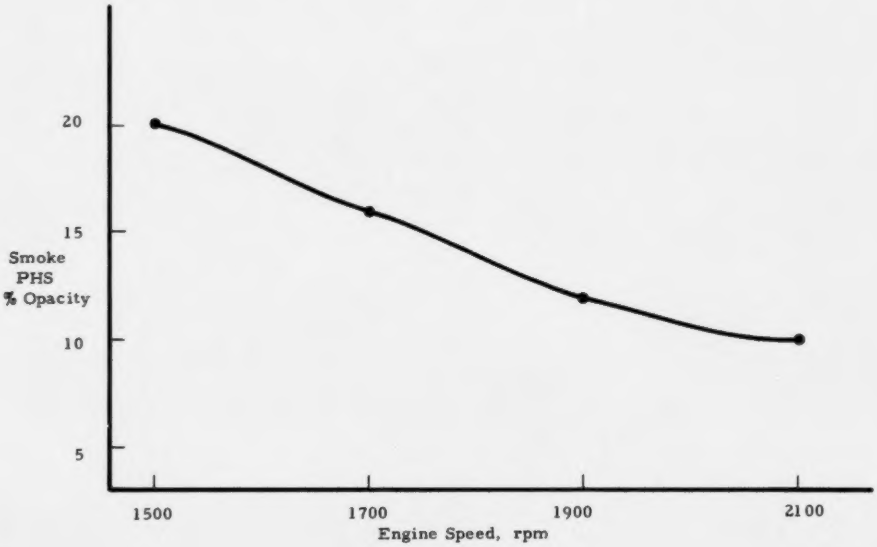


FIGURE 21. SMOKE FROM TYPICAL IN-SERVICE TRUCK-TRACTORS POWERED BY N/A AND T/C FOUR-STROKE ENGINES WITH BOSCH TYPE FUEL INJECTION EQUIPMENT(92, 115)

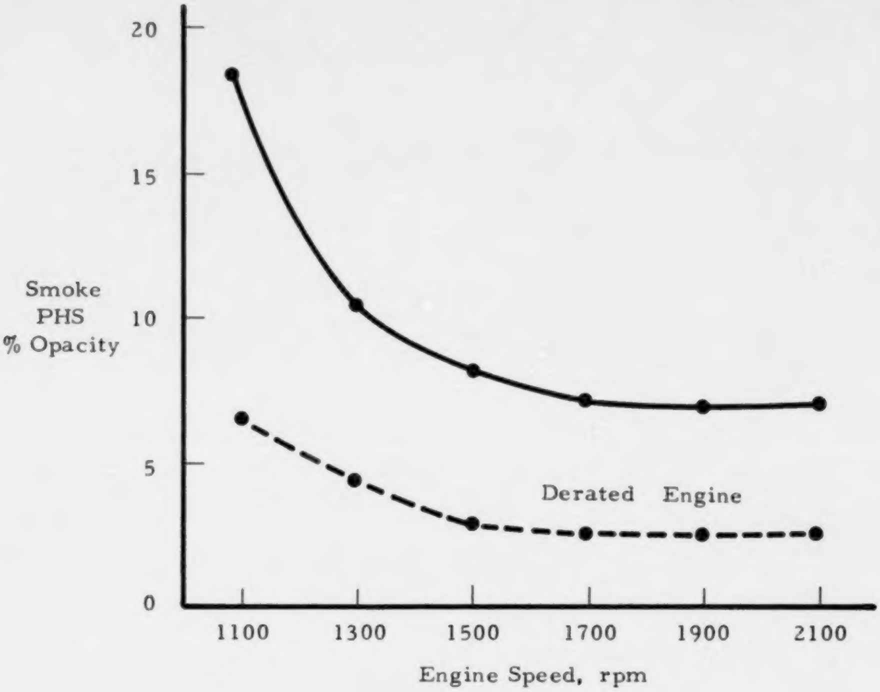


FIGURE 22. SMOKE FROM A TYPICAL IN-SERVICE TRUCK-TRACTOR POWERED BY A TWO-STROKE N-TYPE ENGINE(92)

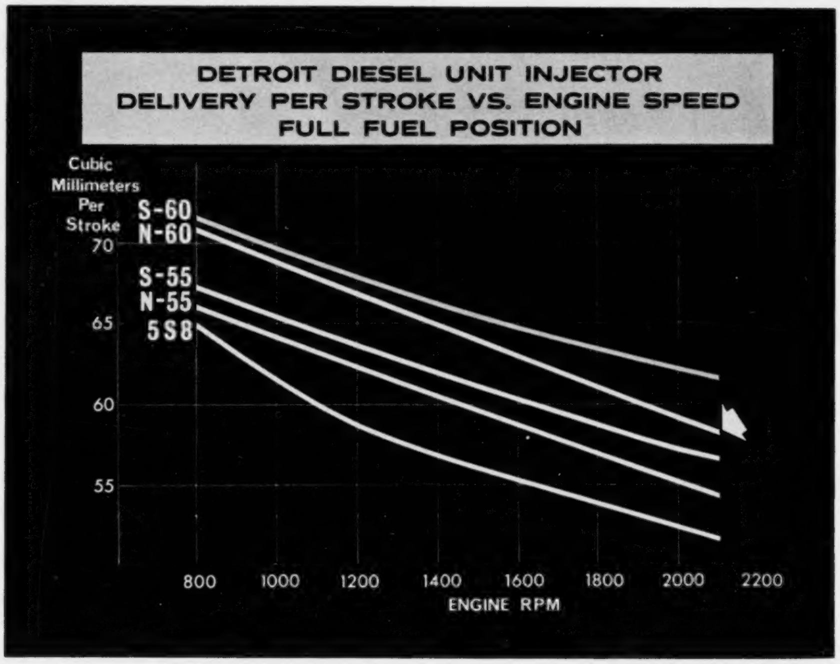


FIGURE 23. UNIT INJECTOR (TWO-STROKE ENGINE) FUEL DELIVERY CHARACTERISTICS(136)

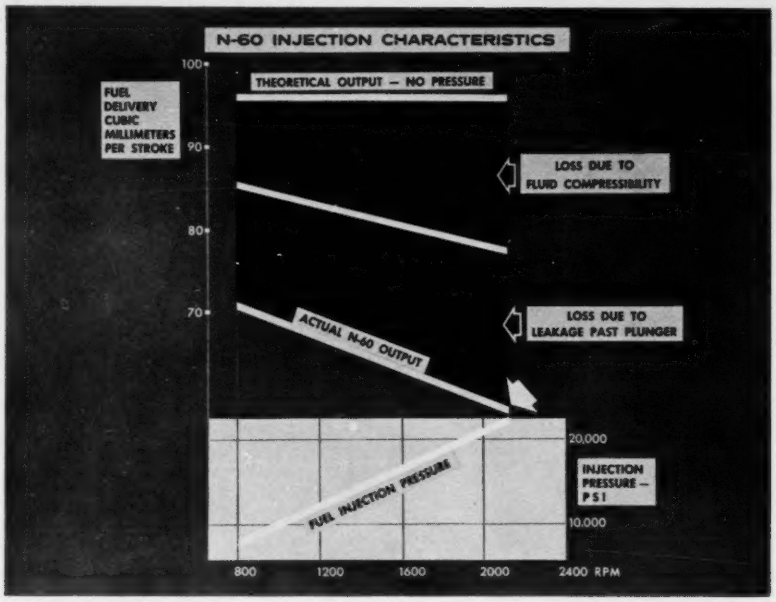


FIGURE 24. REASONS FOR TWO-STROKE ENGINE UNIT INJECTOR FUEL DELIVERY CHARACTERISTICS(136)

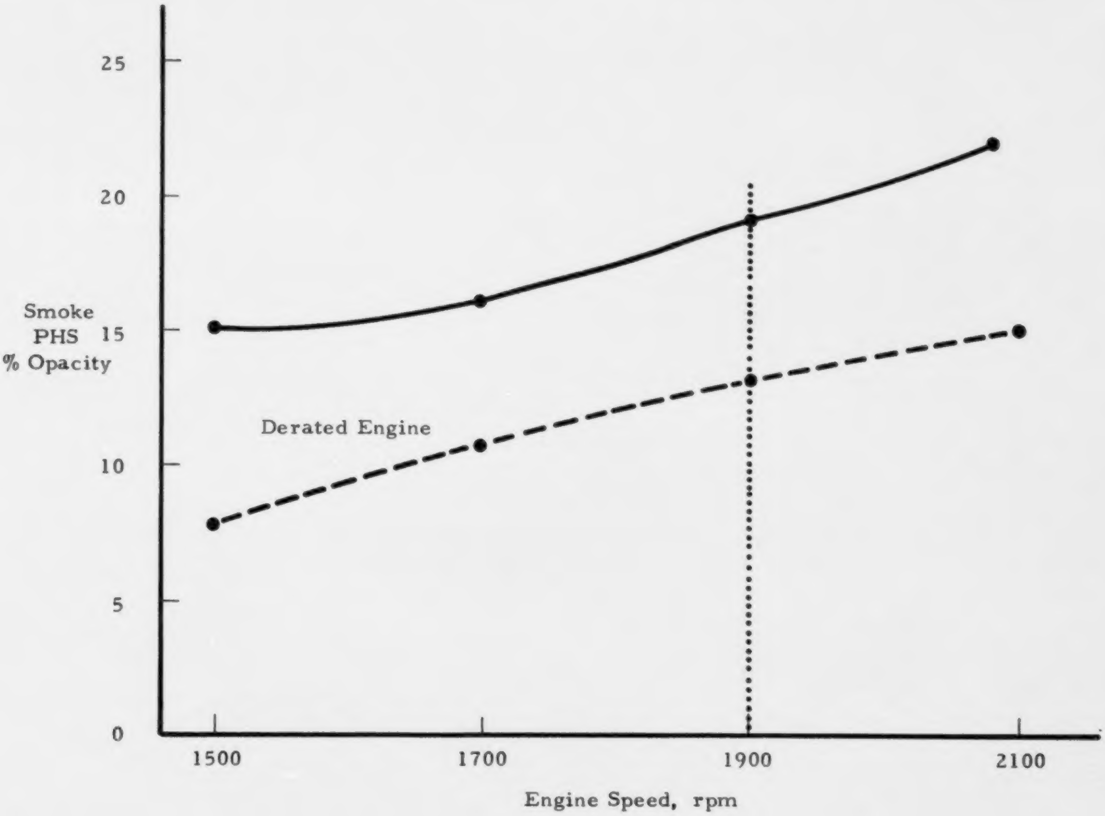


FIGURE 25. SMOKE FROM A TYPICAL IN-SERVICE TRUCK-TRACTOR POWERED BY A FOUR-CYCLE ENGINE WITH A PT PUMP(115)

have found that reducing the maximum recommended or rated speed from 2100 to say 1900 rpm, as shown by the dotted line in Figure 25, results in prolonged engine life.(3, 133) It also "lops off" the upper portion of engine operation most conducive to smoke emission. The more usual method of derating is to reduce the available power by reducing the amount of fuel injected per stroke. Derating a six-cylinder, two-stroke engine about 20 hp by changing from N-65 to a smaller injector resulted in the dashed line shown in Figure 22.(92) Recalibration of the pump of an NH-220 to give an approximate 20-hp reduction resulted in the dashed smoke curve(92) shown in Figure 25. Derating has been shown very effective on most all engines which have a moderate to high smoke tendency as shown in Figure 26.(93)

In any event, derating an engine requires changes to the engine such as injector replacement, fuel pump calibration, and governor setting, or a combination and, if done in the field, should be accomplished at an authorized service center. From discussions with fleet operators and trucking associations, it is apparent that many operators have found that the slight increase in cost and possibly the increased engine weight associated with purchasing a derated engine are more than compensated for on a strict economic basis(3, 126, 134, etc.), not to mention a reduction in smoke emissions. Some engine manufacturers offer turbocharger kits for their naturally aspirated engines which will permit operating them at the same power output but with improved fuel economy and less overall smoke. If they are added to an existing engine to raise the power output, this will result in little or no reduction in smoke.

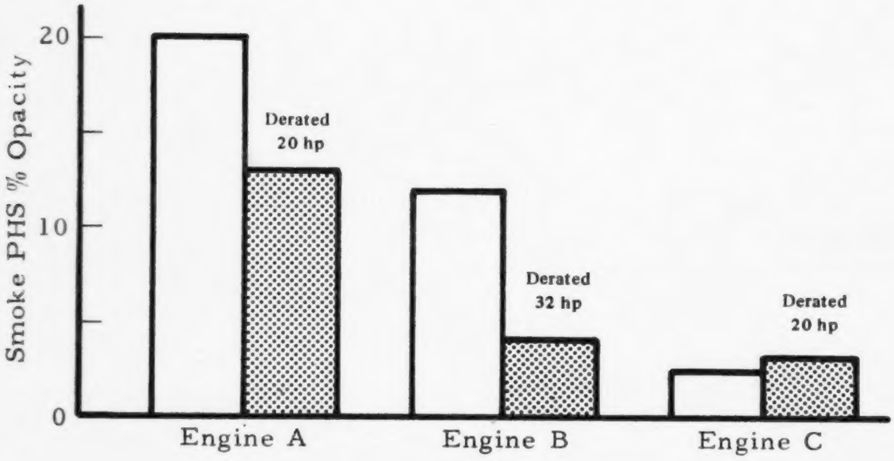


FIGURE 26. EFFECT ON ENGINE DERATING ON EXHAUST SMOKE(92)

C. Fuel System Maintenance Affects Smoke

One of the advantages of the automotive diesel engine is its ability to operate at high horsepower levels for long periods of time with little or no attention. When maintenance is necessary, it is generally with respect to the fuel injection system or air intake system (covered in the next section).

Next to air cleaner maintenance, care of the fuel injection system has the most pronounced effect on engine smoke.(90, 137) It is probably the one portion of the diesel engine which is subjected to more abuse and misuse than any other. It includes the fuel tank, delivery and return lines, primary and secondary filters, transfer and injection pumps, and injectors. An excellent article(138) on fuel filters for diesel engines was recently published and is recommended for helpful hints on their design, application, and maintenance. The injection system on those engines which use the "unit type" injector includes the mechanical (camshaft, pushrod, rocker arm) assembly which actuates the injector. An injector normally operates successfully for over 100, 000 miles and requires replacement or rework once each year to once every 3 years.(3)

Injectors act to mechanically atomize the liquid fuel by forcing it under very high pressure through small holes at a prescribed time during the combustion cycle. Whatever happens during operation to alter spray pattern, injection timing, or fuel charge may alter engine performance and the visible smoke.(90) Injectors that are sticky, or worn so that they do not seal tightly, or have lost their preload due to wear, or have otherwise become sloppy and do not permit clean, sharp injection with full spray pattern development, can increase smoke and odor.(139) Likewise, carbon or other deposits on the injectors will disturb the spray pattern and will cause increased smoke.(139)

To minimize odor and smoke, some maintenance departments have a rigorous program for periodic injector replacement and repair. Bench test equipment is used to flow-balance and match injector delivery rate, spray pattern, and penetration.(3, 140) Some operators have developed special calibration equipment for setting the fuel delivery characteristics of injectors to give optimum fuel economy based on previous operating experience. A few operators recalibrate all injectors, including new ones, while other operators match injectors in sets to give uniform flow and spray characteristics.(3) Bench test equipment is also used to flow-check and calibrate injection pumps on a periodic basis.(140) Figure 27 shows various special bench test facilities in use for rebuilding, testing, and flow-balancing unit injectors and injection pumps. The net effect is to control the tolerances such that fuel is injected into each cylinder in the same way. These operators feel very strongly that the additional cost of maintenance pays dividends in engine life and fuel consumption, as well as reduced smoke and odor.

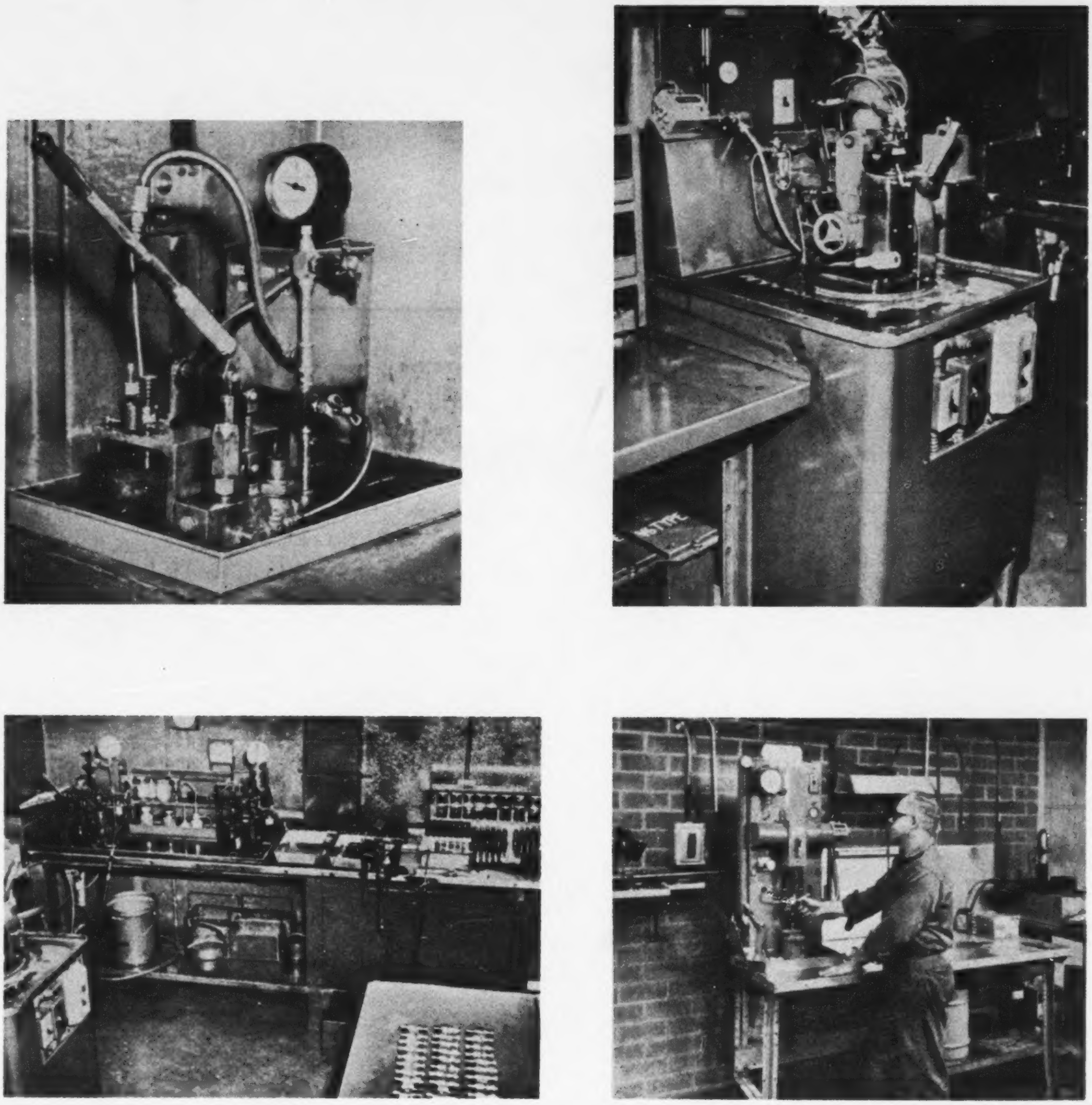


FIGURE 27. FUEL INJECTION OVERHAUL AND TEST EQUIPMENT(140)

Injection systems which use "unit" injectors may have a number of wear points in the mechanism which actuates the injector.(3, 136) These operate from the camshaft of the engine such that, when wear occurs, injection becomes later and later. As illustrated in Figure 28, this wear is a direct function of mileage.(136) The net effect is that the fuel is delivered into the combustion chamber later than desired. Late injection results in higher smoke, and, for some engines, this is most pronounced at low to moderate engine speeds (Figure 29)(29), while, in others, it is more pronounced at higher engine speeds, as shown in Figure 30.(78) Merely cleaning or replacing the injectors is only part of the maintenance necessary to the injection system, and correct adjustment according to the manufacturer's specifications should be strictly followed. In some instances, special dial indicator timing tools may be required as shown in Figure 31.(136)

In some applications where injection timing deteriorates more rapidly than the injector, it is desirable to check timing and adjustments more often or to advance the timing slightly to compensate for wear.(3, 136) Slight advances in timing should be accomplished with judgment and caution as it tends to increase the peak pressures within the engine and, depending on application, could result in slightly less engine life. The improvement in smoke intensity obtained by changing timing, injectors, and engines in a municipal bus is illustrated in Figure 32.(137) The change from the "S" type injector to the "N" type injector is of principal interest and has been confirmed by others.(3, 94, 115) Of equal importance is that, by simply changing to the "N" injectors in an E series engine, there is almost the same improvement in smoke as changing to the N series engine. Detroit Diesel has recently made available a new "N" injector spray tip assembly which replaces the older "N" spray tip as described in the service information bulletin reproduced as Figure 33.

Because of the extremely close tolerances, often 0.00008 in.(138), and fine machined fits of the injection equipment, fuel cleanliness cannot be overemphasized. Most fuels hold a small amount of sediment and abrasive material in suspension which should be removed before the fuel enters the injection equipment. Most engine designs include at least one or more filters to protect the injection system from dirty fuel. The primary filter, which is a strainer of relatively coarse mesh, usually is located on the suction side of the transfer pump (between the fuel supply tank and the transfer pump). A main filter of much finer mesh is located on the pressure side of the transfer pump and screens fuel before it reaches the injection pump. Sometimes, small filter elements are built into the injection pump and injection nozzles themselves for additional protection. The fineness of the filter increases as the fuel comes closer to the injection nozzle. Fuel filters consist generally of a housing, cover, and a filter element.(141) There is a definite trend to replaceable element type filters and from there to the spin-on-type.(138) Cutaway sketches of some fuel filters are shown in Figure 34.(138)

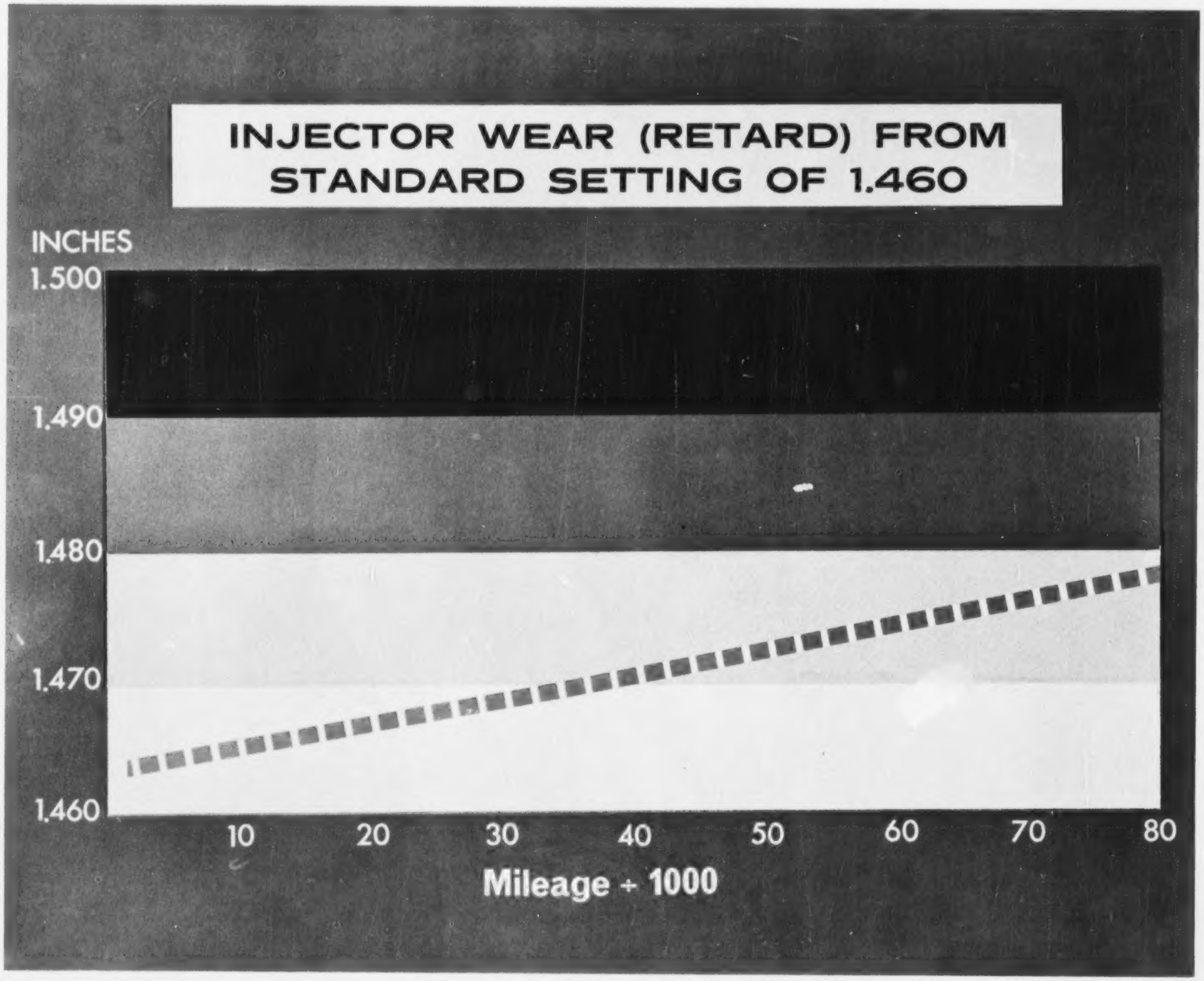


FIGURE 28. EFFECT OF MILEAGE ON INJECTOR WEAR(136)

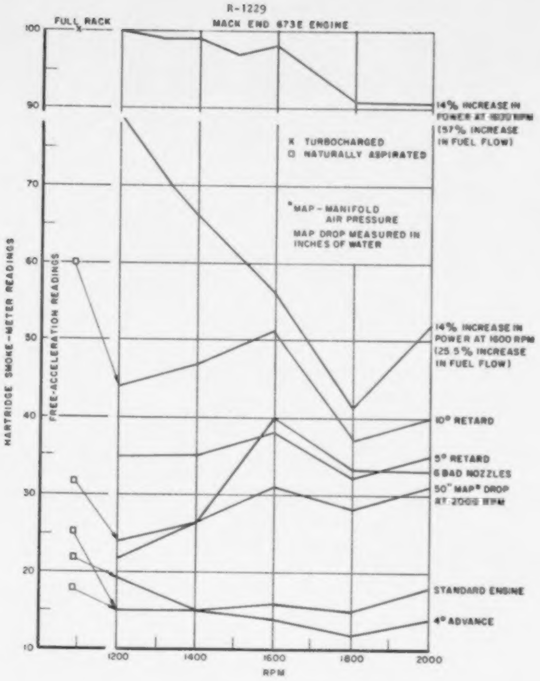


FIGURE 29. EFFECT OF INJECTION TIMING ON SMOKE FROM FOUR-STROKE N/A ENGINE(29)

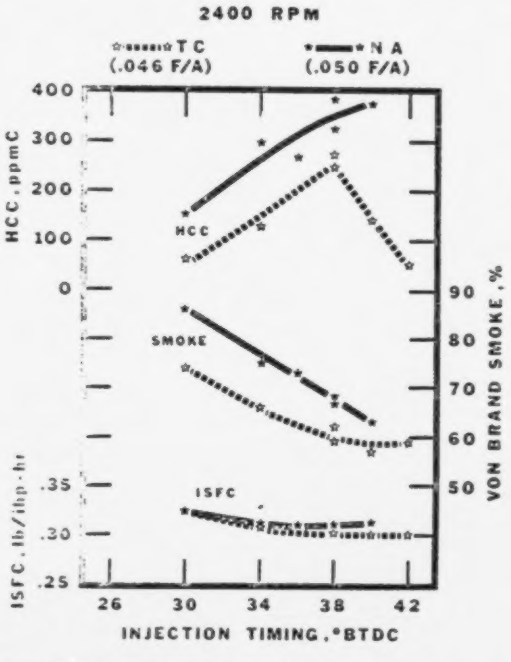


FIGURE 30. EFFECT OF INJECTION TIMING ON SMOKE FROM T/C AND N/A FOUR-STROKE ENGINE AT 2400 RPM(78)

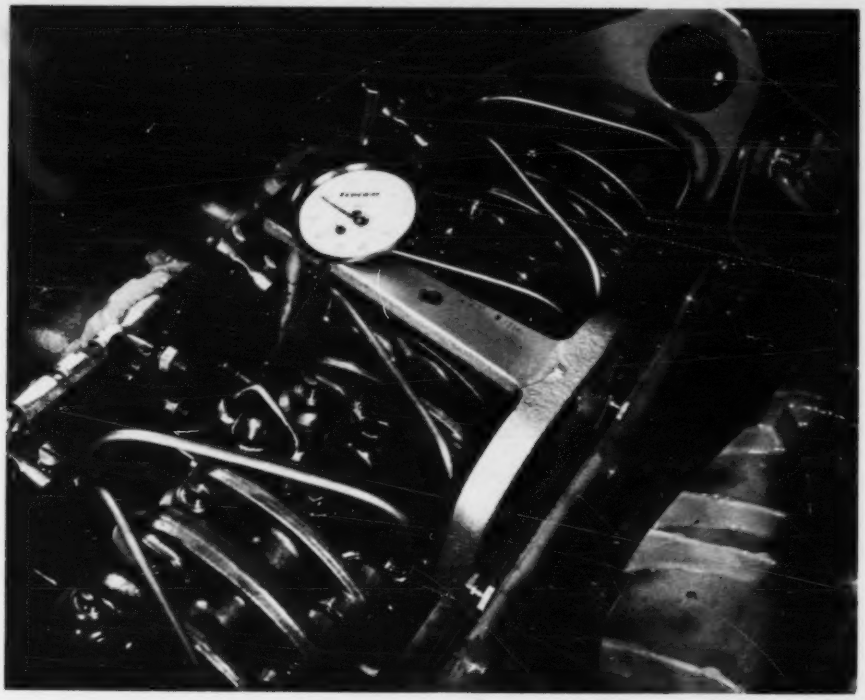


FIGURE 31. TWO-STROKE ENGINE UNIT INJECTOR ADJUSTMENT(136)

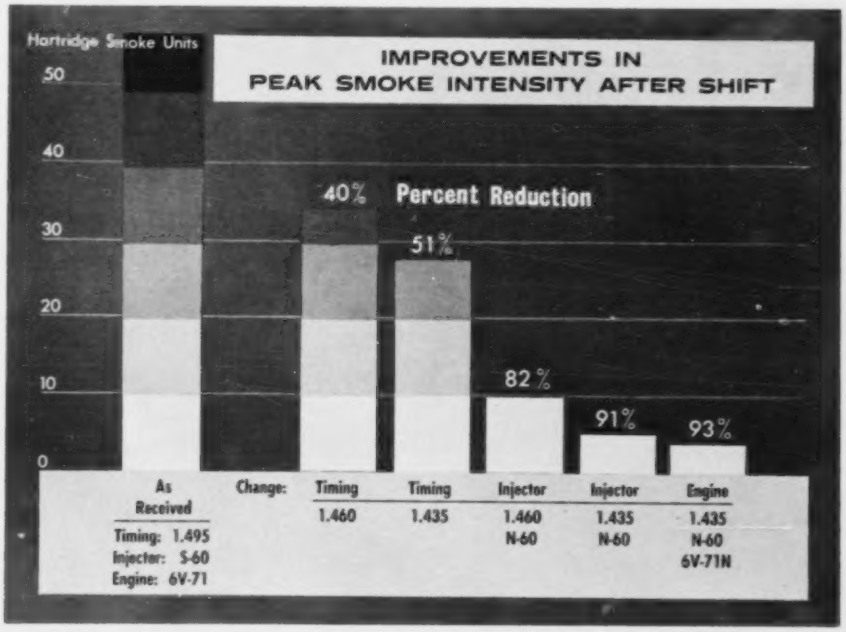


FIGURE 32. EFFECT OF INJECTOR TYPE AND ADJUSTMENT ON SMOKE(136)

PLEASE DESTROY SERVICE BULLETIN 69-I-12 Dated 6-20-69

SERVICE | INFORMATION BULLETIN

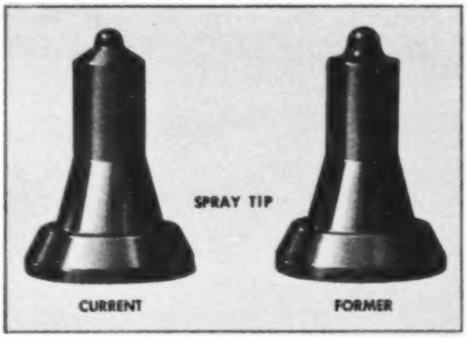
M. M. REF.: 2.1.1 NUMBER: 69-I-12 Revised

DATE: 6/27/69 SERIES: 53 and 71

SUBJECT: NEW "N" INJECTOR SPRAY TIP ASSEMBLIES

New spray tip assemblies are now used in all "N" injectors. The current injector tip has a reduced volume of fuel below the needle valve. Also the current "low sac volume" spray tips differ from the former spray tips in appearance (see illustration).

Only the current spray tip assemblies are serviced and they are completely interchangeable with the former spray tip assemblies. The injector assembly part numbers will not change.



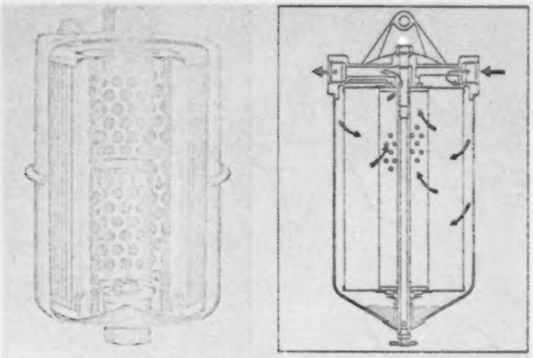
PARTS LIST

Current	Former	Part Name	Number of Holes	Hole Size
5229026	5228768+	Spray Tip Assy., Injector	8	.0055
5229030	5228853+	Spray Tip Assy., Injector	8	.006
5229042	5228778+	Spray Tip Assy., Injector	7	.006
5229034	5228747+	Spray Tip Assy., Injector	6	.006
5229048	5228794+	Spray Tip Assy., Injector (Multifuel)	6	.006

+Not Serviced

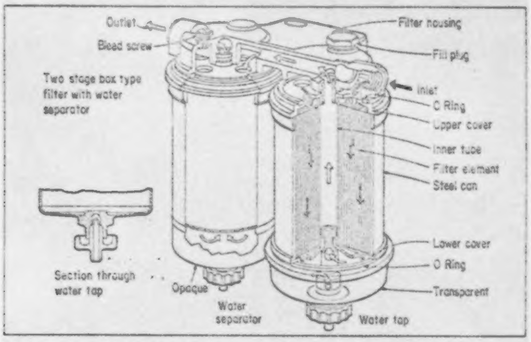
Service Publication Department
Detroit Diesel Engine Division
General Motors Corporation

FIGURE 33. NEW "N" INJECTOR SPRAY TIP ASSEMBLIES



American Bosch final stage filter is of the throw-away type and very similar to modern in-line gasoline filters.

Fleetguard throw-away fuel filter for Cummins engines is the only filter used in the fuel system.


Outlet
Bleed screw
Two stage box type filter with water separator
Section through water tap
Opaque
Water separator
Water tap
Filter housing
Fill plug
Inlet
O Ring
Upper cover
Inner tube
Filter element
Steel can
Lower cover
O Ring
Transparent

Robert Bosch diesel fuel filter has paper element first, followed by depth type element. The sump is transparent so amount of water can be seen.

FIGURE 34. TYPICAL FUEL FILTER CONFIGURATIONS ON DIESEL-POWERED VEHICLES(138)

In addition to routine cleaning or replacement of the fuel filters, periodic cleaning or draining of the vehicle fuel tanks is recommended. The suction pipes through which the fuel is drawn from the tank should clear the bottom of the tank to avoid picking up water and sediment. Dispensing and storage tanks must be included in a successful fuel cleanliness program.(142) One operator found it advantageous to keep the storage tanks as near full as practical to eliminate moisture buildup.(3)

With the advent of diagnostic centers and electronic analyzers for diesel engines, improved maintenance and inspection programs are possible, with repairs being quality control tested to make sure all necessary repairs have been made correctly and that nothing is left to chance.(143, 144) Some service shops utilizing chassis dynamometers now direct the exhaust smoke into the open so that the mechanic making adjustments can observe the smoke plume while the vehicle is under typical speed and power conditions.

D. Induction and Exhaust System Maintenance Affects Smoke

It has been indicated that air-fuel ratio has a substantial bearing on the smoke characteristic of a diesel engine and that good fuel system maintenance is essential. Obviously, if air-fuel ratios are to be correct, the air induction system requires attention also. For every gallon of fuel, more than 12, 500 gallons of air are required in the diesel.(125) Maintenance of both the induction and exhaust systems of the engine are generally more straightforward and easier to accomplish than the fuel injection system, and, for this reason, they are sometimes discounted or overlooked. Many times, the injectors are blamed for poor performance, excessive smoke, or odor when it is the induction or exhaust system which needs attention. The general effects of inlet and exhaust restrictions on smoke and power were shown as trend curves in the "Guide" (Figure 10) and are presented slightly differently in this report as Figures 35 and 36. The trends were drawn on the basis of interviews(3) and selected other references.(125, 145)

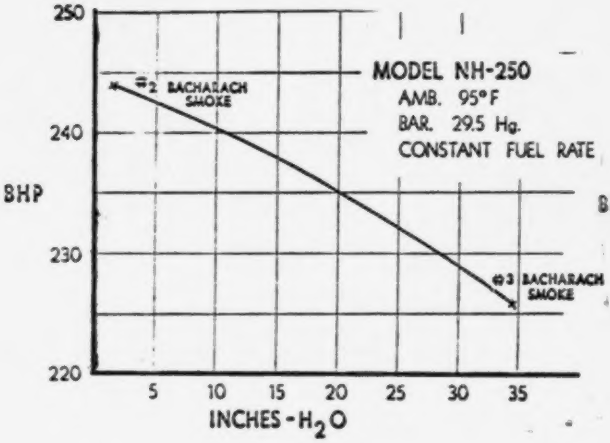


FIGURE 35. EFFECTS OF INTAKE RESTRICTION(125)

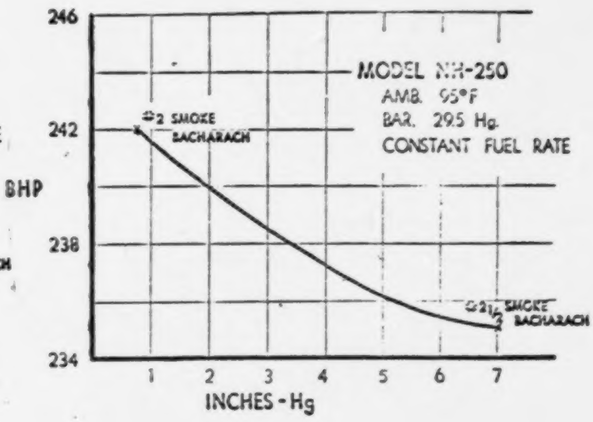


FIGURE 36. EFFECTS OF EXHAUST BACKPRESSURE(125)

As can be seen from Figure 35, the induction system is considerably more sensitive and has a more pronounced effect on power and smoke than has the exhaust system (Figure 36) for this popularly used truck-tractor engine. Not only does the inlet system affect smoke on many engines, it can also be a definite economic penalty in terms of available power from the engine. Exhaust restrictions have less effect. As an example, a pressure drop of 35 in. of water air inlet restriction caused a power loss from 244 to 226 hp with a change in smoke from a Number 2 to a Number 3 Bacharach. An exhaust back pressure of 7 in. of Hg (95 in. of water) reduced power from 242 to 235 hp with the smoke increasing from a Number 2 to a 2. 5 Bacharach, as shown in Figure 36.(125) Some engines are quite sensitive to intake and exhaust restrictions (four-stroke naturally aspirated, for example); other engines, such as the two-stroke, are relatively insensitive to small changes in inlet or exit restrictions as far as either smoke or power are concerned. Exhaust restrictions, however, tend to increase exhaust temperatures and make scavenging of the combustion chamber during the exhaust stroke less efficient.

Vehicle and engine manufacturers work together during design and installation to insure that induction and exhaust systems do not penalize performance and increase exhaust emissions.(3) Generally, the location of the air cleaner is not critical provided sufficient outside air is allowed into the engine. In extremely cold weather, it is desirable to provide an under-hood air inlet since low air intake temperatures can increase ignition lag and reduce combustion efficiency.(125) If the air cleaner is too small or the inlet becomes obstructed in some way, the engine will not induct sufficient air, producing a lower air-fuel ratio than necessary and increasing smoke. For this reason, the induction system must be designed in such a manner that ice or snow will not obstruct the inlet. Further, water can impair the performance of most filters by forming mud or ice on them, or even literally disintegrating some paper type filters.(3, 125, 146) Proper maintenance of the air filters is a must for low smoke operation.(125, 146-148) From personal interviews(3), it was learned that the largest truck fleet, Consolidated Freightways, was considering elimination of air filters.(149) So far, no difficulty has been encountered with a single two-stroke powered tractor under test. Further experiments with two- and four-stroke engines are planned. Since this is contrary to most engine manufacturers' recommendations and other operators' experience, this practice cannot be recommended at this time, though the results should be interesting. Some fleet operators specify oversize air filters on new equipment(3) and feel this is a more attractive alternative.

The induction system may include a turbocharger which may act as a partial inlet restriction during certain types of operation, particularly acceleration from idle. In laboratory studies(92), it was found that certain turbocharged engines with smoke opacities of 10 to 20 percent under "lug-down" exhibited 40 to 50 percent opacity under acceleration from idle, while engines with 25 to 40 percent opacity during "lug-down" had 95 to 100 percent opacity under acceleration. This increase in smoke under acceleration, particularly from idle, is normally related to the lag in the turbocharger speed in relation to engine speed(150) and thereby not deliver a full cylinder air charge. Because of the increased volume of air handled by the turbocharger, cleanliness of the air filter and inlet piping is particularly important.(151, 152)

The effect of inlet air temperature is important particularly for naturally aspirated engines, since the density of the air is directly related to temperature (see Table 4). At elevated temperatures, an increase in air consumption or a decrease in fuel consumption should be accomplished to adjust the air-fuel ratio.(153-154) There is a limit, however, on the low air intake temperatures, and, below 10°F, the increased ignition lag and lower combustion efficiency make it desirable to provide an under-hood air inlet to help preheat the air.(125) Altitude, likewise, can have considerable effect on smoke with naturally aspirated engines since air density decreases with rising elevation.(131, 155) The effect was shown in an earlier section.

Inlet and exhaust valving also plays an important part in the ability of an engine to breathe and its resultant smoke production. If valve underheads become clogged with deposits, an internal restriction higher than normal may develop. This was reported by a few operators with certain designs of the two-stroke engine in stop-and-go municipal service.(3) Worn valve guides and bushings and piston rings and liners can permit excessive oil consumption which can produce blue smoke in addition to black smoke. Persistent blue smoke under cruise conditions may mean that a major overhaul is needed.

Service or shop manuals are supplied by every manufacturer of engines or vehicles and contain a wealth of information on maintenance practices to control smoke. References 156 to 159 are good examples of the type of maintenance manuals available. These manuals include troubleshooting aids for determining the cause of smoke and detailed specifications and tolerances on working parts. The fleets that have made use of these as a guide to establishing preventive maintenance programs and the training and upgrading of diesel mechanics have been able to reduce odor and smoke.(3)

E. Effect of Driver Technique on Smoke

Driving procedure has, in most instances, been either taken too lightly, overlooked entirely, or discounted as a factor in the production of diesel odor and smoke. From a number of interviews with drivers, driver supervisors, and fleet operators, one fact was clearly evident, and that is that most drivers associate smoke with power. For example, during a recent 6-month fleet test of a diesel smoke suppressant additive(92), a truck had to be put on the chassis dynamometer to prove to the driver that his power was still there even though the smoke was a fraction of what it was. He and several other drivers were convinced that their trucks had lost power. The basis for this association is related to the performance specifications for the engines themselves. As shown earlier in Figure 17, the relation between horsepower and smoke is such that smoke does increase with power. When an engine cannot take in more air to support the combustion of additional fuel, the generally small increase in horsepower is at a very high cost in both smoke and fuel consumption. The point that must be put over to drivers is that black smoke always means overfueling or incomplete combustion and not power. "Lugging" or underspeeding certain engines, for example, can cause smoking.

Several articles appear in the literature(160-161) that illustrate what ultimately occurs when drivers "diddle with their diesels." The most common practice of drivers for increasing fuel delivery on some engines is to restrict the fuel return line and increase the delivery pressure with the results shown in Figure 20. Other practices include changing the governor settings or fuel pump pressures. Though some fuel controls and engines are less prone to adjustment enroute than others, the ingenuity of drivers seems to have been superior to even the most tamperproof systems. The end result of these adjustments is shortened engine life and possible smoke citations, if they're not soon found and corrected.

Rather than make road adjustments to increase the level of smoke, the driver should report and persist in his complaint of poor performance to the maintenance and driver supervisor until the cause is found and remedied. The increasing use of chassis dynamometers and diagnostic equipment(143, 144) has been helpful in finding causes as well as reconciling power complaints. The driver should be encouraged to operate within the manufacturers' recommended speed range.

There is no doubt that drivers can also affect smoke emissions without resorting to road adjustments.(125, 139, 162-165) The principal "don't" most often mentioned in the literature is "lugging" or underspeeding the engine by the driver. By changing to a lower gear, thus increasing the engine speed, smoke from the types of engines shown in Figures 21 and 22 can be reduced. The effect of feathering the accelerator pedal while going through the gears is another technique the driver can use to help reduce smoke. This was quite evident on a visit to the Castaic dynamometer site in California. The use of a mirror, aimed at the exhaust discharge, allows the driver to view the smoke and control the emissions to a considerable extent. The use of a mirror is recommended by both engine manufacturers and operators(3, 166) and is easily used on vertical stack equipped conventional cabs. More difficulty is encountered on cabover and horizontal exhaust equipped vehicles.

With an engine in poor mechanical condition, or one that is too small for the job, the driver may have no alternative but to operate in a smoking condition when trying to keep traffic flow orderly or negotiate a hill. Current policies with several of the large fleet operators is that the operator pays for smoke citations issued.(3) For driver-owners, the greatest or perhaps only incentive for reduced smoke may well be a citation. Many people(3) believe that, ultimately, driver effects will be eliminated by the use of derating, rack limiters, automatic transmissions, and improved engine design.

F. Effect of Fuel on Smoke

"The physical characteristics of fuels influence physical processes in fuel injection and in fuel-air mixing, and in affecting these processes, fuel characteristics do influence emissions. However, differences in emissions due to differences in fuel physical characteristics can be removed by adjusting engines for any given fuel. Thus, the general conclusion is that in conventional diesel fuels, fuel composition, per se, has small to negligible effect upon diesel emissions." This is the conclusion of Mr. R. W. Hurn of the Petroleum Research Center of the U. S. Bureau of Mines after many years of research on the effects of fuels on diesel emissions.(167)

Because of the vast interest in diesel fuels, however, the literature contains more information on fuel and fuel properties and their relation to diesel emissions than any other area. The complexity of the fuels themselves, the numerous engines in service with their varied designs, compression ratios, injection characteristics, etc., and the operating mode under which the engines are tested, all add to the numerous conflicting or apparently conflicting findings in the literature. Even though this section will be largely out of proportion to its relevance to smoke and odor control, it is thought appropriate that as many of the literature sources as possible be considered. It should be pointed out, however, that most engines are designed for a particular fuel(167-169), not only from the combustion point of view, but also from a lubricating consideration, and, therefore, engine manufacturer's fuel recommendations should not be taken lightly.

The interest in diesel fuels is as old as the diesel itself. In 1918, the Bureau of Mines issued Bulletin 156 entitled, "The Diesel Engine - Its Fuels and Its Uses."(170) Fuel specifications and recommendations were made for aliphatic, aromatic, and vegetable fuel oils. Fuels continue to be of interest, although on some points there is confusion and disagreement. For all operating conditions of a specific engine, it is not clear exactly what influence a change in fuel properties will have on smoke.(171) While some contend that diesel fuels are better than necessary(172), the search continues for upgrading fuels, additives, etc. It's been estimated that objectionable smoke can be formed if as little as 1 percent of the full-load fuel delivery is converted into carbon.(173) Thus, fuel and fuel properties have been considered important in reducing smoke by increasing combustion efficiency.

Diesel fuel is usually available as a Number 1 which is a light or kerosene type fuel, or as a Number 2 which is a heavier fraction. Number 1 is sometimes used in urban stop-and-go type, moderate duty applications.(3, 168, 174) Number 2, because of lower cost and higher heat content, is used almost exclusively in line-haul trucking and other applications where continuous heavy power demands are made.(3, 139, 141, 168) Current ASTM D975-67 specifications for diesel fuel are listed in Table 5.(175) These can be compared with a recent 1968 Bureau of Mines survey of available fuels as shown in Figure 37.(176) Further study of this survey reveals the wide variation in diesel fuels classed as Number 1 and 2 across the United States in which the Numbers 1 and 2 boiling ranges and cetane ranges almost completely overlap. Fuel specifications for diesel fuels to be used in qualifying engines for 1970 engine certification are shown in Table 6.(6)

TABLE 5. LIMITING REQUIREMENTS FOR DIESEL FUEL OILS*(185)

Grade of Diesel Fuel Oil		Flash Point, deg Fahr (deg C)	Pour Point deg Fahr (deg C)	Water and Sediment, per cent by volume	Carbon Residue on 10 per cent Residuum, per cent	Ash, per cent by weight	Distillation Temperatures, deg Fahr (deg C) 90 per cent Point		Viscosity at 100 F (37.8 C) Kinematic, centistokes (or Saybolt Universal, sec)		Sulfur, per cent by weight	Copper Strip Corrosion	Cetane Number[e]
		Min	Max	Max	Max	Max	Min	Max	Min	Max	Max	Max	Min
No. 1-D	A volatile distillate fuel oil for engines in service requiring frequent speed and load changes.	100 or legal (37.8)	[b]	Trace	0.15	0.01	...	550 (287.8)	1.4	2.5 (34.4)	0.50	No. 3	40[f]
No. 2-D	A distillate fuel oil of lower volatility for engines in industrial and heavy mobile service.	125 or legal (51.7)	[b]	0.10	0.35	0.02	540[c] (282.2)	640 (338)	2.0[c] (32.6)	4.3 (40.1)	0.7[d]	No. 3	40[f]
No. 4-D	A fuel oil for low and medium speed engines.	130 or legal (54.4)	[b]	0.50	...	0.10	...	...	5.8 (45)	26.4 (125)	2.0	...	30[f]

[a] To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller, and supplier.

[b] For cold weather operation, the pour point should be specified 10 F (5.6 C) below the ambient temperature at which the engine is to be operated except where fuel oil heating facilities are provided.

[c] When pour point less than 0 F (−17.8 C) is specified, the minimum viscosity shall be 1.8 cs (32.0 sec, Saybolt Universal) and the minimum 90 per cent point shall be waived.

[d] For all products outside the U.S.A. the maximum sulfur limit shall be 1.0 per cent by weight.

[e] Where cetane number by Method D 613, Test for Ignition Quality of Diesel Fuels by the Cetane Method,[2] is not available, ASTM Method D 976, Calculated Cetane Index of Distillate Fuels[2] may be used as an approximation. Where there is disagreement, Method D 613 shall be the referee method.

[f] Low-atmospheric temperatures as well as engine operation at high altitudes may require use of fuels with higher cetane ratings.

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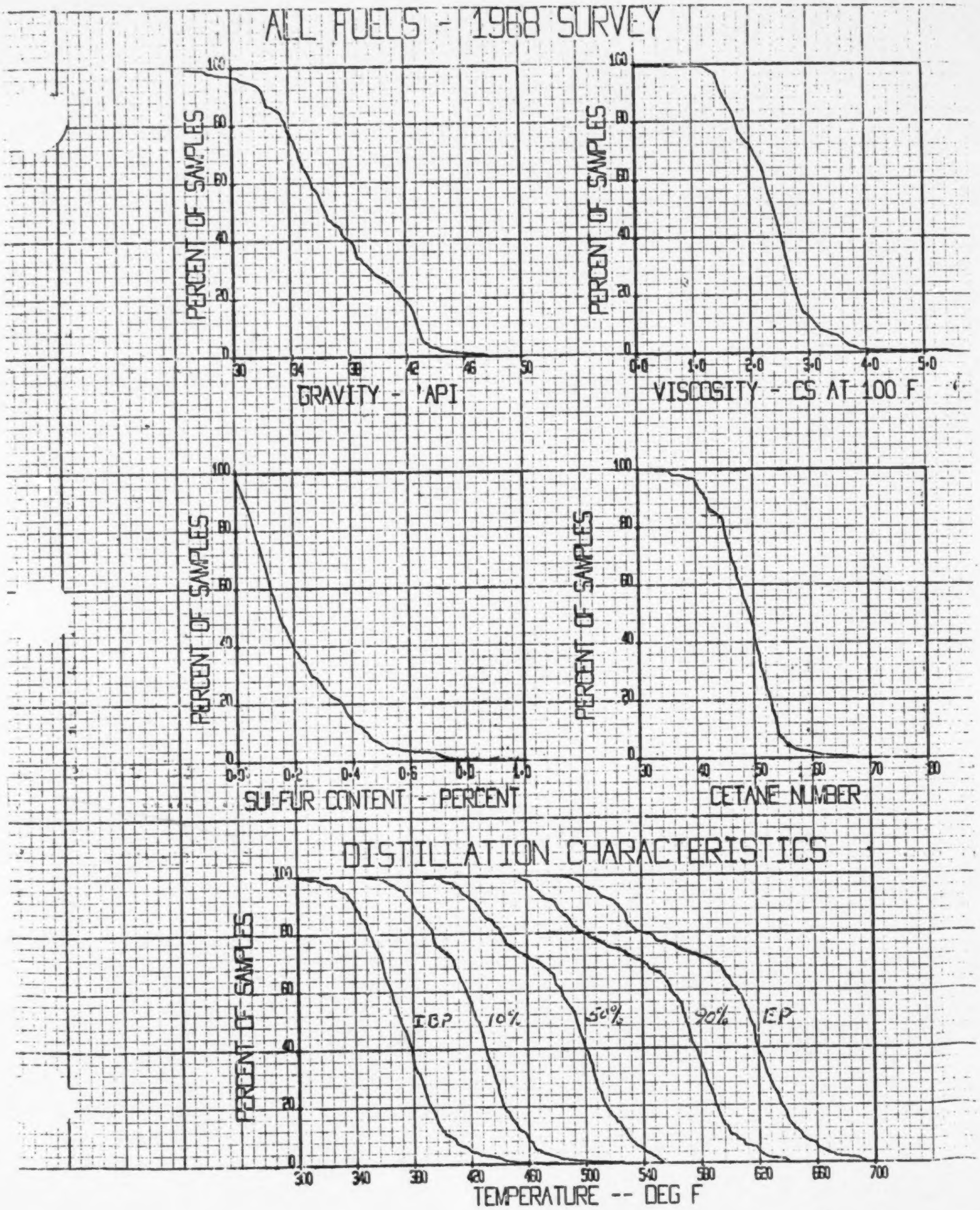

FIGURE 37. BUREAU OF MINES SURVEY OF DIESEL FUELS(176)

TABLE 6. FUEL SPECIFICATIONS FOR EXHAUST EMISSION TESTING IN 1970 ENGINE QUALIFICATIONS(6)

Item	ASTM test method No.	Type 1-D	Type 2-D
Cetane	D 613	48-54	42-50
Distillation range	D 86		
IBP, ° F		330-390	340-400
10 percent point, ° F		370-430	400-460
50 percent point, ° F		410-480	470-540
90 percent point, ° F		460-520	550-610
EP, ° F		500-560	580-660
Gravity, ° API	D 287	40-44	33-37
Total sulfur, percent	D 129 or D 2022	0.05-0.20	0.2-0.5
Hydrocarbon composition	D 1319		
Aromatics, percent		8-15	27 (Min.)
Paraffins, Naphthenes, Olefins		Remainder	Remainder
Flash point, ° F (Min.)	D 93	120	130
Viscosity, centistokes	D 445	1.6-2.0	2.0-3.2

1. Smoke Formation

The nature of the formation of solid carbon and its particles during the combustion of hydrocarbon fuel is still not completely understood, and no completely satisfactory explanation is available for their presence in exhaust gases.(177, 178) When a droplet of fuel is heated in a diesel engine combustion chamber, there is usually sufficient oxygen surrounding the droplet to enable oxidation of the hydrogen and carbon to occur. However, should there be insufficient oxygen, too little time, or other conditions unfavorable for complete combustion, the hydrogen will preferentially react with the available oxygen leaving the carbon unreacted.(173, 178) A decrease in gas temperature in the combustion chamber, owing to cooling by fuel droplets and by the chamber walls, also tends to prevent complete combustion, and incomplete combustion causes smoke.(177)

2. Effects on Smoke

The four most often mentioned fuel properties relating to emissions are volatility, gravity, viscosity, and ignition quality or cetane rating.(168, 173, 178, 179) Volatility and gravity are normally interrelated in that the lighter more volatile fuels are less dense than the heavier, higher boiling point fuels.(168) Volatility or distillation range is a measure of the vaporization characteristics of the fuel. Gravity or density is a measure of the specific gravity or mass per unit volume of fuel. Gravity, however, should rarely be a controlling specification item since it is usually set by the crude source, refining processing, boiling range, and cetane number requirements established at the refinery.(168, 180) Substitution of a low boiling range, low gravity, Number 1 diesel fuel for the heavier, higher boiling range, Number 2 fuel in a diesel engine without fuel rate adjustment will result in noticeably less smoke.(168, 173, 179, 181-183) This is not accomplished, however, without a loss in power and, as such, is a type of derating.(173) Although this phenomenon has been attributed singly to the increased volatility, the principal reasons have been related to (1) lower viscosity, which may allow greater leakage of the fuel past the plunger(136, 173) and (2) reduced mass delivered because of the lower specific gravity of the Number 1 fuel. When the weight differences are corrected, or the engine is derated with the heavier fuel, the differences in smoke emissions disappear, as shown in Figure 38.

Fuel composition or hydrocarbon type has been shown to be an important consideration for smoke generation in two investigations.(174, 178) Two Number 2 fuels covering a wide range in hydrocarbon composition revealed the smoke characteristics in Figure 39 for the two-stroke and four-stroke engines. Further examination of these fuels are shown in Table 7, however, indicates a substantial difference in specific gravity (0. 82 for fuel A as opposed to 0. 88 for fuel B). This difference could be more important than the composition, although the aromatics are considered by some to smoke more.(171, 178, 179) There is not complete agreement in the effect of aromatics in commercial diesel fuel or diesel smoke.

In general, the distillation range of the first 10 percent of the fuel (light ends) should be low enough to insure sufficient volatile material for easy starting in cold weather. The final boiling points should be high enough to give full power and economy. However, if they are too high, crankcase dilution, carbon deposits, and excessive smoke may result.(141, 168, 184, 185)

Viscosity is a measure of a fuel's resistance to flow. Viscosity has a direct bearing on fuel droplet size, hence, the fuel evaporation rate, spray pattern, and spray penetration. Viscosity can also have an effect on the wear rate of pumps and injectors because the fuel acts as the lubricant for these parts. For all practical purposes, the rather narrow range of viscosities found in available diesel fuels (1. 4 to 4. 17 centistokes(186)) indicates viscosity, per se, has little direct influence on combustion unless misapplied to a given type engine.(168) Such an extreme case would be the use of a heavy fuel oil with a viscosity causing excessively large droplets which actually impinged on and wetted the cylinder walls. As already mentioned, too low a viscosity will allow leakage of the fuel past the plunger(136, 173) allowing less weight to be delivered which can result in less smoke.

Ignition quality or cetane rating is usually more important from one engine design to another than it is within one specific engine. One report(168) indicated that some engines are insensitive to a change of 10 cetane numbers, whereas others are more sensitive. This same reference reported cetane number to have practically no effect on full-load smoke, power, or economy. In most high speed engines, the minimum requirement for satisfactory operation is between 40 and 45 cetane numbers with black exhaust smoke being fairly independent of the ignition quality between 40 and 60 cetane.(90, 168, 179, 187)

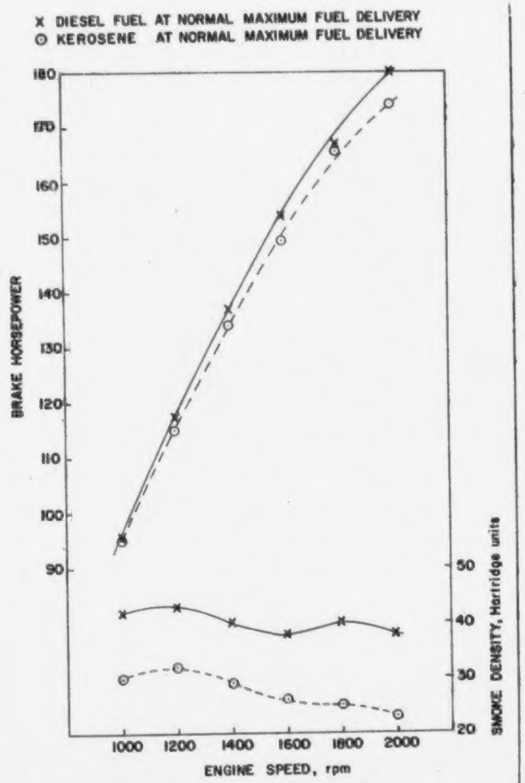

FIG. 7 **Effect of using kerosene** instead of diesel fuel at normal maximum fuel delivery (127-mm bore x 145-mm stroke, 6 cyl, direct injection engine). Bhp is reduced throughout speed range by the lighter fuel. To which is credited the fact there's less black smoke.

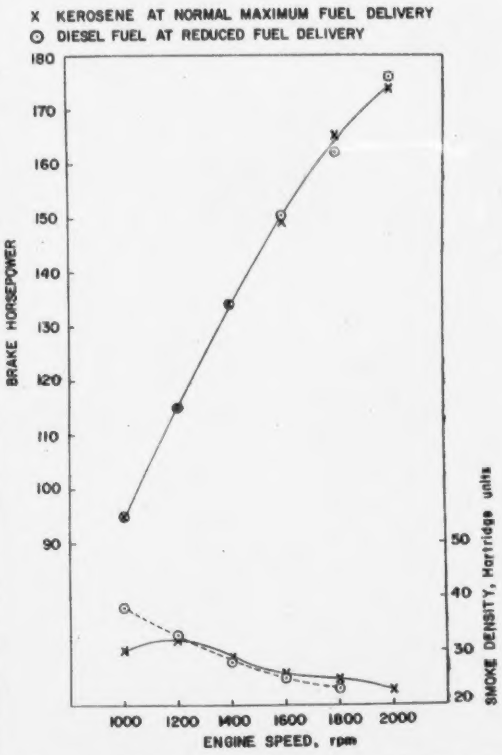

FIG. 8 **Power and exhaust smoke from de-rated engine** using diesel fuel versus full rated engine using kerosene (same 6-cyl engine as in Fig. 7). Light fuel and heavy fuel create the same amount of smoke if the fuel pump is set to a lower delivery with the heavier fuel.

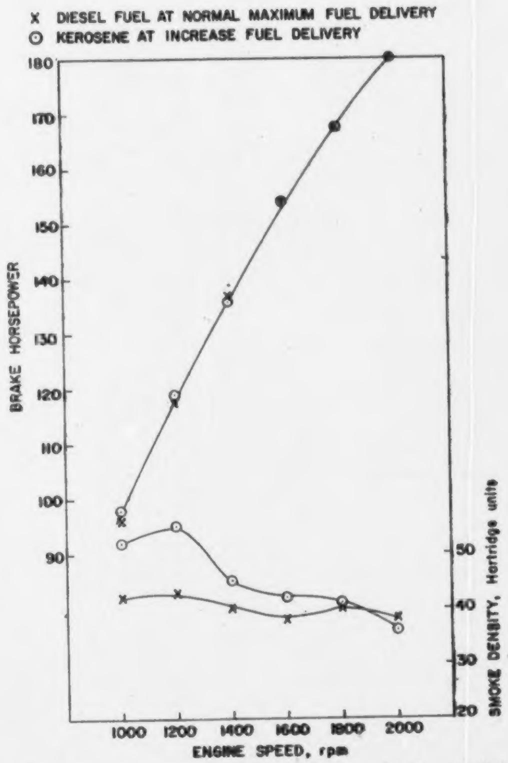

FIG. 9 **Power and exhaust smoke realized when using kerosene fuel** at increased fuel pump delivery versus a diesel fuel at normal delivery (127-mm bore x 145-mm stroke, 6 cyl, direct injection engine).

FIGURE 38. SMOKE EMISSION CHARACTERISTICS FOR SPECIFIC GRAVITY CORRECTIONS(173)

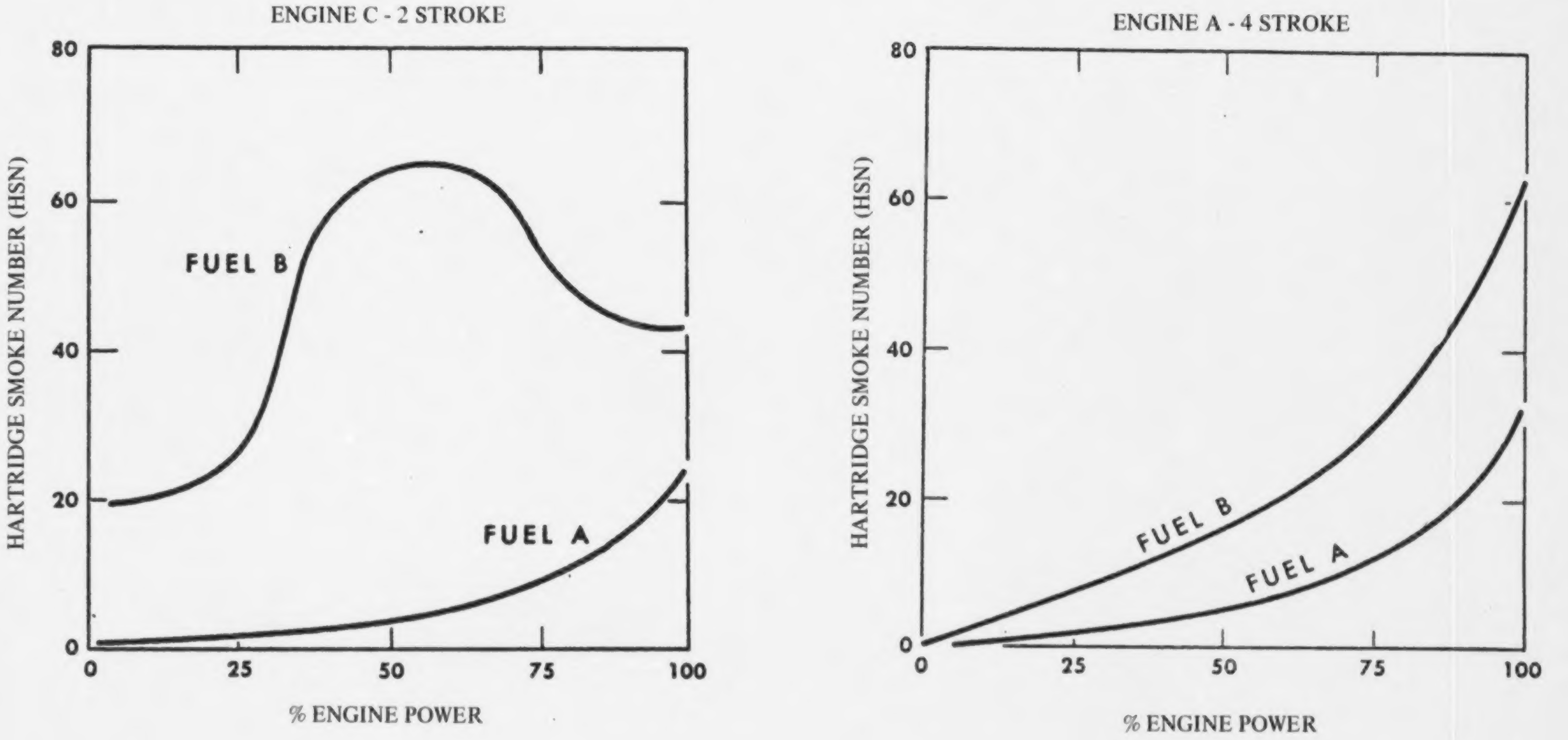

FIGURE 39. SMOKE CHARACTERISTICS AS A FUNCTION OF FUEL COMPOSITION(174)

TABLE 7. HYDROCARBON COMPOSITION AND FUEL PROPERTIES OF FUELS IN FIGURE 39(174)

Fuel	A	B
Description	Straight-Run Distillate	Catalytically-Cracked Stock
Distillation, °F		
10% Evap.	400	440
50% Evap.	490	530
90% Evap.	590	600
Specific Gravity	0.824	0.882
Gravity, °API	40	29
Cetane Number	58	41
Sulfur, percent	0.2	0.7
Hydrocarbon Type, percent (FIA)		
Aromatics	16	47
Olefins	T	2
Paraffins	84	51

Fuel should be obtained free of foreign matter such as water, dirt, or other particulates, and its quality should be uniform and dependable. Although quality fuels are available from all major producers, contamination may occur in storage where moisture and corrosion can build up in fuel lines and tanks.(141, 168) The fuel system maintenance already described cannot be overemphasized to insure clean fuel to eliminate corrosion, wear, and plugging of injectors and lines.

Numerous fuel additives have been used in diesel fuels for a number of years. Compounds such as amyl nitrate(188) and dinitropropane(181) have been used as cetane improvers. Another ignition accelerator (improver) reported to provide excellent cold startability (and thereby reduce cold smoke) has been metallic sodium(189); practical handling techniques, however, have not been reported. Other additives have included special agents such as antioxidants(190), corrosion inhibitors(190, 191), detergents(190, 191), biocides(190, 192), and others. A partial list is presented in Table 8.

More recently, a number of commercial diesel fuel additives for reduction of visible smoke have become available. Smoke has been reduced to between one-half to one-fourth of its original value(93, 193) in one naturally aspirated four-stroke engine by merely adding additives of the "barium-type" to the fuel as shown in Figure 40.(93) The improvement is almost instantaneous and has been demonstrated throughout extended fleet

TABLE 8. PARTIAL LIST OF DIESEL FUEL ADDITIVES(190)

Supplier	*Designation*	*Active ingredient*	*Dosage lb./1000 B*
Antioxidants			
Ethyl	703	A	—
DuPont	FOA-3	B	5-15
Amoco	508	U	10-50
UOP	Polyflo 122	U	—
Corrosion inhibitors			
Monsanto	Santolene C	C	2-10
Detergents			
Monsanto	Santolene K	U	20-30
UOP	Polyflo 100	U	—
UOP	Polyflo 120	U	—
Metal deactivators			
DuPont	DMD	D	0·2-3
Amoco	521	D	1-2
Monsanto	Santolene M	U	0·5-12
Cetane no. improver			
Ethyl	D11	E	(0·1-0·5%)
Smoke suppressor			
Lubrizol	565	U	(0·25-0·5%)
Multipurpose			
Ethyl	MPA-D	U	58
Anti-icers and/or Biocides			
Phillips	PFA 55MB	F	(200-1000 ppm)
Sohio	Biobor JF	G	(135-270 ppm)

A—2,6-di-tert-butyl-dimethylamino-p-cresol
B—mixed organic amines
C—linoleic acid dimer
D—N,N′-disalicylidene-1,2-propylene diamine
E—mixed amyl nitrates
F—ethylene glycol monomethyl ether plus glycerine
G—organoboron compounds
U—unknown

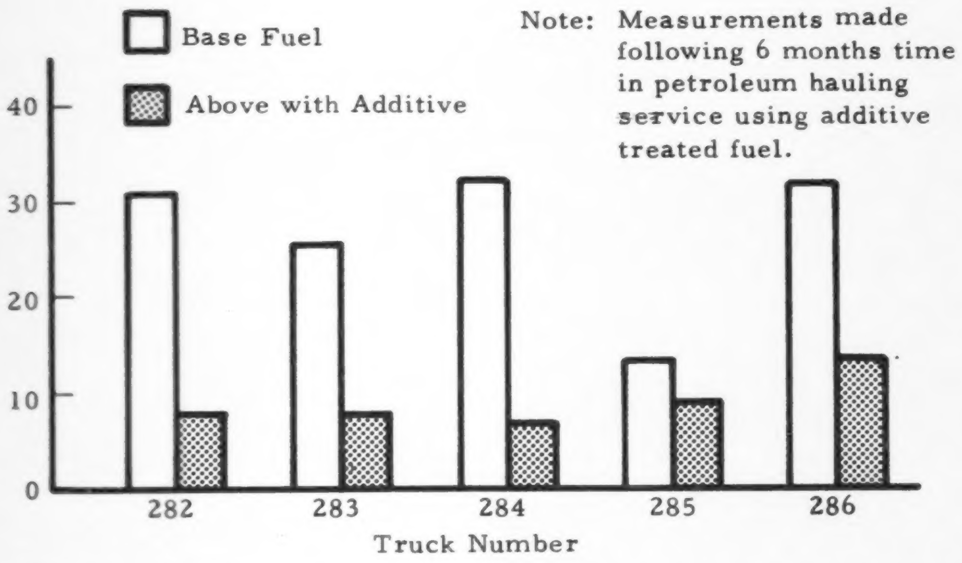

FIGURE 40. EFFECTS OF A SMOKE SUPPRESSANT FUEL ADDITIVE ON VISIBLE EMISSIONS FROM FIVE SIMILAR DIESEL TRACTORS--MAXIMUM POWER AT 2100 RPM(93)

tests of a popular four-stroke N/A engine to have no adverse effect on engine performance, injector wear, engine deposits, or other maintenance factors. (92, 93, 135, 179, 184, 194-197)

The mechanism by which the barium additive works has been investigated, and it is thought to act as a fuel stabilizer to inhibit the formation of carbon. (198, 199) Other smoke suppressant additives have been investigated which contain compounds of manganese, lead, cobalt, and nickel. (57, 197) Investigation of a large number and variety of experimental and proprietary additives in typical diesel engines, however, has shown that the barium type is the most effective. A typical before-and-after sequence of truck smoke with and without the barium type additive is shown in Figure 41. Although not an additive, as such, hydrogen-treated fuel has been shown to prolong injector life and thereby reduce exhaust smoke and maintenance costs. (200)

Although premium diesel fuels are offered by several refiners, Atlantic-Richfield diesel fuel is currently the only known premium diesel fuel supplied in the U. S. with the barium smoke suppressant. (201, 202) Union Oil markets a canned additive in its stations. (3, 203) Others are currently marketing a smoke suppressant in Europe. (204, 205) Mixed reactions to the premium grade fuels have been expressed(206), although premium accounts for half of Richfield's sales. (201) This may be influenced by the active enforcement of diesel smoke regulations in California.

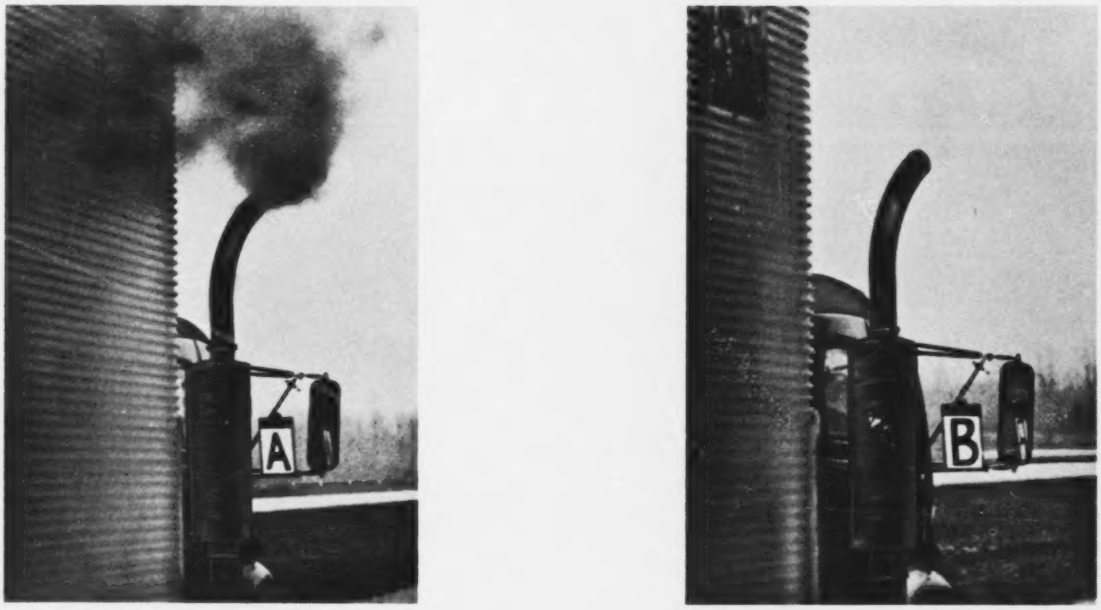

FIGURE 41. TYPICAL SMOKE REDUCTION USING THE BARIUM TYPE ADDITIVE

The increase in fuel cost of 1 to 2 cents per gal (dependent on quantity purchased) for the more effective additives(3, 201, 202, 206, 207) is viewed by a number of operators as prohibitive and they prefer other means to reduce smoke. Some use fuel treatment as a temporary means or only in certain areas until corrective action can be taken. At fuel mileage between 4 and 6 miles per gal, the increased cost of 1 to 2 cents per gal adds about 0.3 cent per mile or about 5 percent to the normal 6 cents per mile(125) engine operating cost.

The barium additive is also an excellent dispersant and will suspend water and sediment in the fuel which sometimes will tend to plug the primary filter. It has been known to effectively loosen deposits and residue in storage tanks. Atlantic-Richfield recommends thorough cleaning of all tanks before use(3) to eliminate filter plugging. In addition to reducing smoke, tests have shown that injector life has been extended with the barium type additives with the potential for lower maintenance costs.(142, 194, 196, 201) The use of fuel additives other than those approved by the manufacturer may void the engine warranty of some makes. There is concern that certain additives, including the barium type, may result in products of combustion, the effects of which are not completely understood in the atmosphere and human body. From available information, health effects appear to be minimal(179, 208) though not completely substantiated.

G. Effect of Control Devices on Smoke

A number of devices and techniques have been offered to reduce smoke emissions. The effect of turbocharging, discussed previously, is beneficial, particularly during cruise type conditions. The use of rack limiters or aneroid controls with turbocharged engines control the fueling rate during acceleration and is a definite aid in minimizing smoke during these transient conditions. Some manufacturers offer turbocharging kits which have been added by some operators to existing engines. Although the kit permits uprating the engine power, this is usually not done when full smoke reduction potential is desired.

Dual fuel or fumigation systems utilizing liquid petroleum gas (LPG) have found limited application in diesel trucks. These systems meter a small amount of fuel into the intake manifold to initiate precombustion reactions which help the diesel fuel injected into the combustion chamber to burn better. Ever since the early work done at California Research Corporation(209), fumigation has been regarded as a power boost and possible cure for smoke.(140, 162, 210) LPG and gasoline have been most widely used, although alcohol, hexane, heptane, ethers, benzene, and peroxides(209-214) have been investigated. It is generally recognized that the secondary fuel eliminates smoke by inducing pre-flame reactions and shortening ignition lag. Typical smoke reduction can be seen in Figure 42.(210) Although most of these systems have been successful in minimizing smoke, the need for

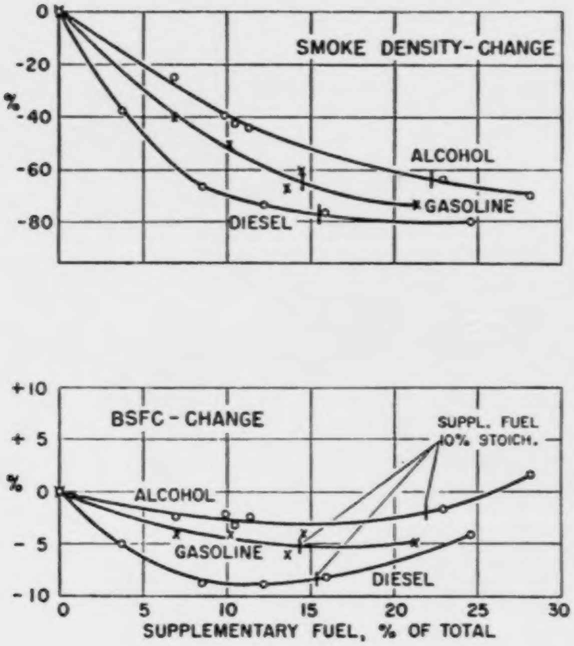

FIGURE 42. EFFECT OF VARIOUS SUPPLEMENTAL FUELS ON SMOKE AND ENGINE PERFORMANCE(210)

two fuel systems has limited their popularity. In discussions with Mr. Max Ellis, who has marketed such a device in California since 1956, shown in Figure 43(215), it was learned that he has not had requests in the last 5 years.(3) It was his understanding that some carburetor manufacturers were offering such a device for construction and farm equipment.

Although diesel fuel appeared promising as a secondary fuel with a laboratory engine operated at low speed(210), additional tests using a popular multicylinder truck engine showed that at low engine speed, the smoke reduction was significant (as much as 80 percent), but, as engine speed increased, smoke improvement decreased. At operating speed, there was essentially no reduction in smoke(92, 93) as shown in Figure 44. Since it is characteristic of this particular engine to produce more smoke with increased speed, and the higher the speed the less effect, this approach was abandoned. Fumigation of the two-stroke engine is not practical because of the large amount of air needed to scavenge the combustion chamber, thus requiring an excess and waste of fumigated fuel.

A number of methods have been tried to modify the appearance of the smoke plume. Some operators directed the smoke down to the vicinity of the drive wheels to dissipate the smoke, only to find the smoke looked worse.(3)

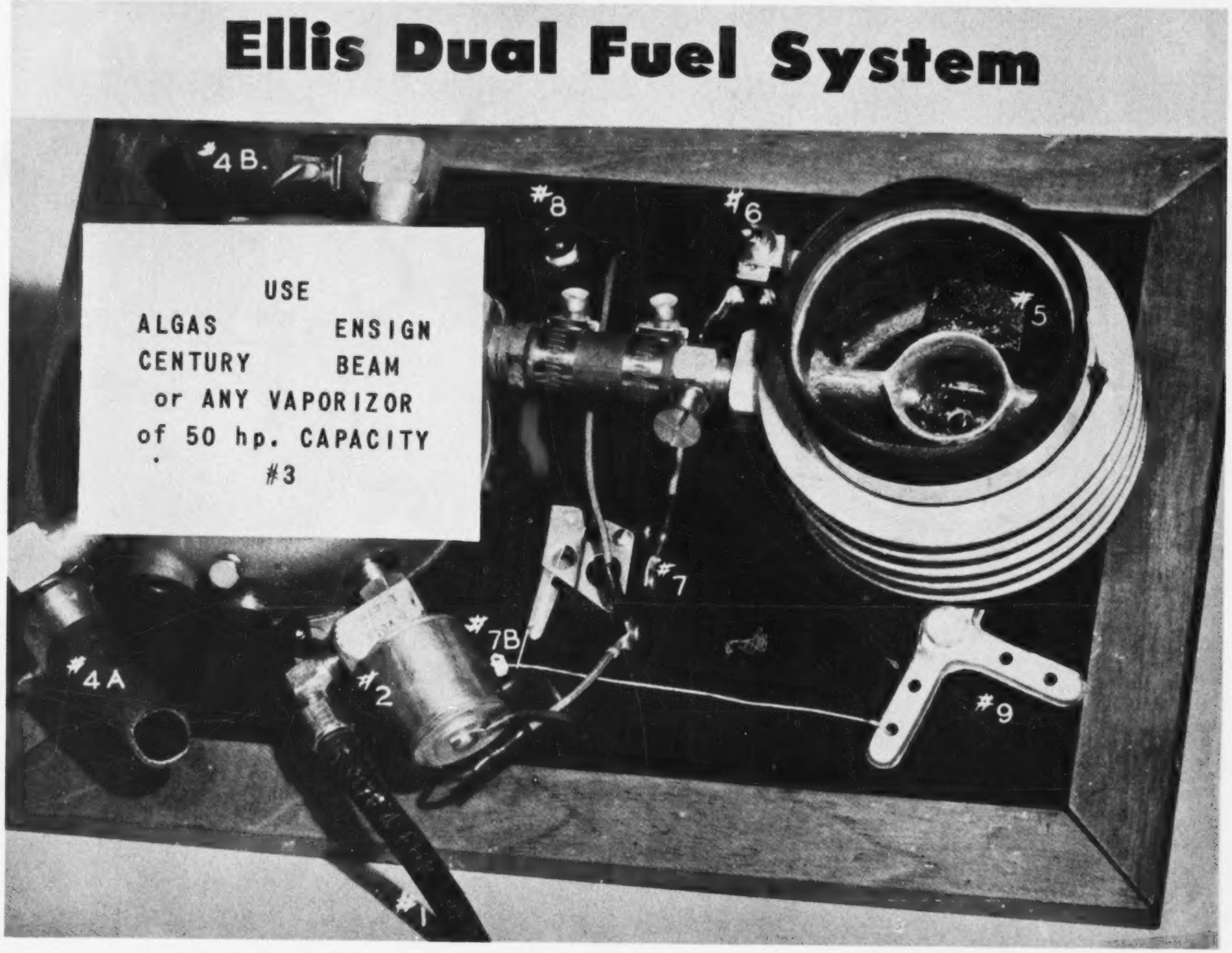
Ellis Dual Fuel System
#4B.
#8
#6
#5
USE
ALGAS ENSIGN
CENTURY BEAM
or ANY VAPORIZOR
of 50 hp. CAPACITY
#3
#7
#7B
#4A
#2
#9
#1

FIGURE 43. ELLIS DUAL-FUEL SYSTEM(215)

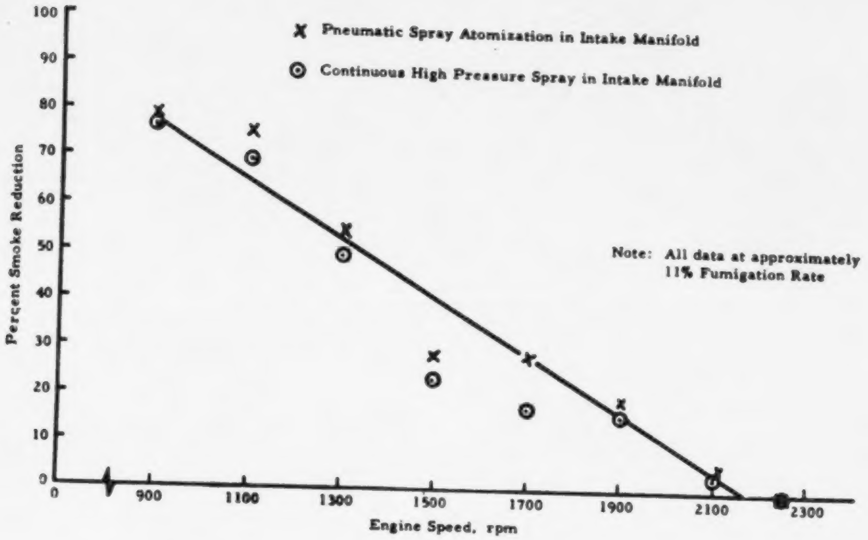

FIGURE 44. EFFECT OF "FUMIGATION" ON EXHAUST SMOKE(93)

In many cases, the downward directed exhaust smoke was not only more noticeable, it obscured visibility of other motorists and, depending on design, entered the vehicle compartment and aggravated the driver. Many operators of properly maintained stop-and-go vehicles have found downward directed or horizontal low-to-the-ground exhaust has been beneficial in downtown operation by keeping the soot near the ground. In combination with condensed water in the tailpipe, the soot, sometimes wetted, does not fall on people and property as much as from the same vehicle equipped with a vertical stack. (3)

Other methods investigated have included adding partially reacted fuel along with the aspirated air(216), or adding fresh air to the exhaust pipe to dilute the smoke(92, 93), or using a number of small pipes to break up the single plume. Small, large, and various shaped pipes with novel arrangements for inducing dilution air have also been tried. None of these have been satisfactory and more times than not made the smoke more noticeable. An interesting design is shown under test in Figure 45, but this approach had no real overall effect. Recent investigations have shown that acceptability depended on both volume and concentration of smoke emitted. The smoke from a small engine (78 Hartridge units) was more acceptable than that from a larger engine (54 Hartridge units). This same research indicated the color of the vehicle could influence opinion with smoke from lighter colored vehicles more apparent and objectionable. (217, 218)

Vehicle retarders such as the Jacobs engine brake(219, 220), which operate during closed throttle engine deceleration by opening the exhaust valves during the compression stroke and causing the engine to operate as a

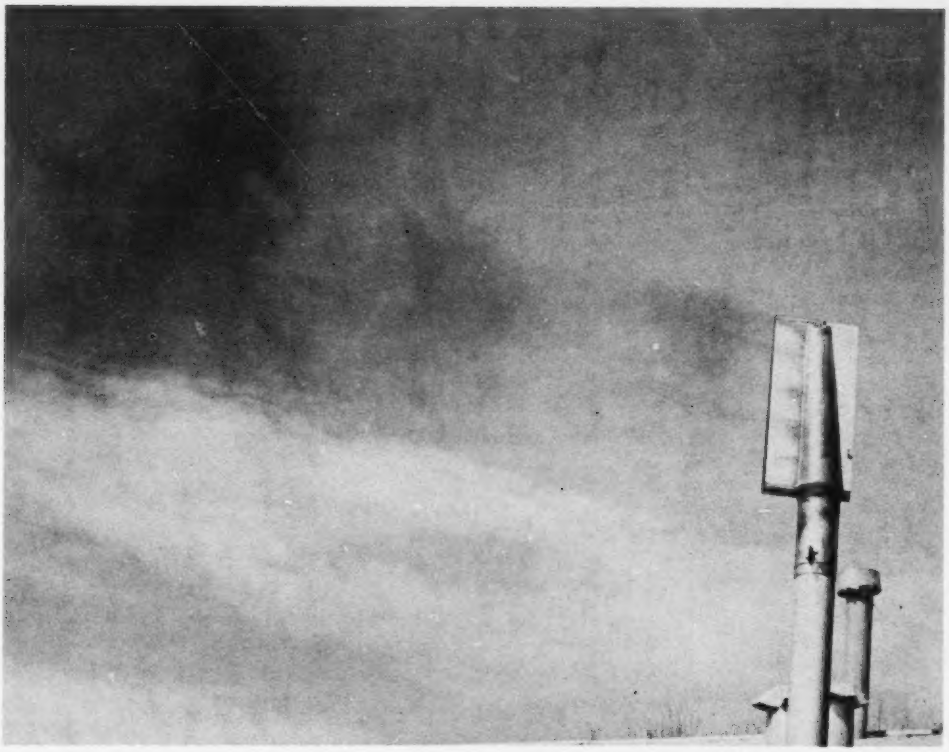

FIGURE 45. EXHAUST SMOKE DILUTION DEVICE(93)

compressor, have been shown to have no effect on smoke from well-maintained engines. (92, 93) Retarders have been reported to help reduce smoking of older, plugged up, engines by cleaning out combustion and exhaust deposits and allowing the engine to breathe normally. (3)

One of the keys to lower odor and smoke in the future may be improved matching of the components in the total drive train from engine to drive tires. The heavy-duty automatic transmission is expected to improve driveability, route speed, and maintenance. Its use may reduce odor and smoke considerably by consistently preventing the engine from being overloaded throughout its speed range. In stop-and-go service, it would seem that several shifts would be better than a few to extract the optimum in reduced odor and smoke.

Passing the exhaust through after burners and catalytic mufflers has been considered at length. To date, these devices lack technical promise for smoke control because of the need for very high temperatures for oxidation of the carbon particulate. Limited tests of preheated air added to the exhaust at the exit of the exhaust valve, much the same as gasoline engine manifold air oxidation, showed only marginal reduction in smoke with a four-cycle engine, Figure 46(95), and no improvement in a two-cycle engine(92), shown in Figure 47.

Electrostatic precipitation of carbon particulates has been tried with diesel exhaust and shown ineffective. The Gourdine Systems, Inc., prototype, developed under NAPCA sponsorship, is shown in Figure 48.(115) The ionizer is shown in Figure 49 after a short test. The carbon particulate quickly coats the interior and short-circuits the system. Mechanical filters and separators have also been proposed for removal of smoke.(221, 222) These methods usually increase exhaust backpressure beyond limits or are gravely inefficient and involve considerable cleaning and repair.

Federal smoke requirements for 1970 diesel engines have been met without external devices or equipment such as those mentioned. The procedure(6) includes a 1000-hr run to demonstrate that the engine will continue to meet the smoke limits with time. Accordingly, the need for external devices for control of smoke from 1970 and later engines to meet Federal smoke levels should not be necessary assuming application, maintenance, operation, and fuel are according to manufacturers' recommendations.

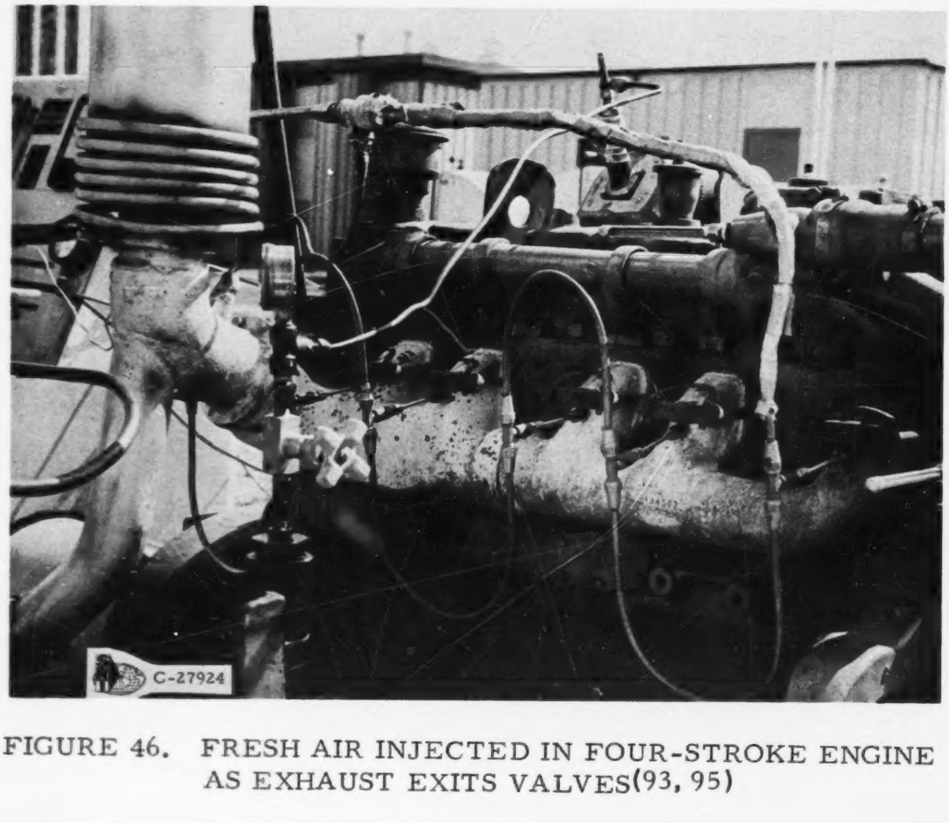

FIGURE 46. FRESH AIR INJECTED IN FOUR-STROKE ENGINE AS EXHAUST EXITS VALVES(93, 95)

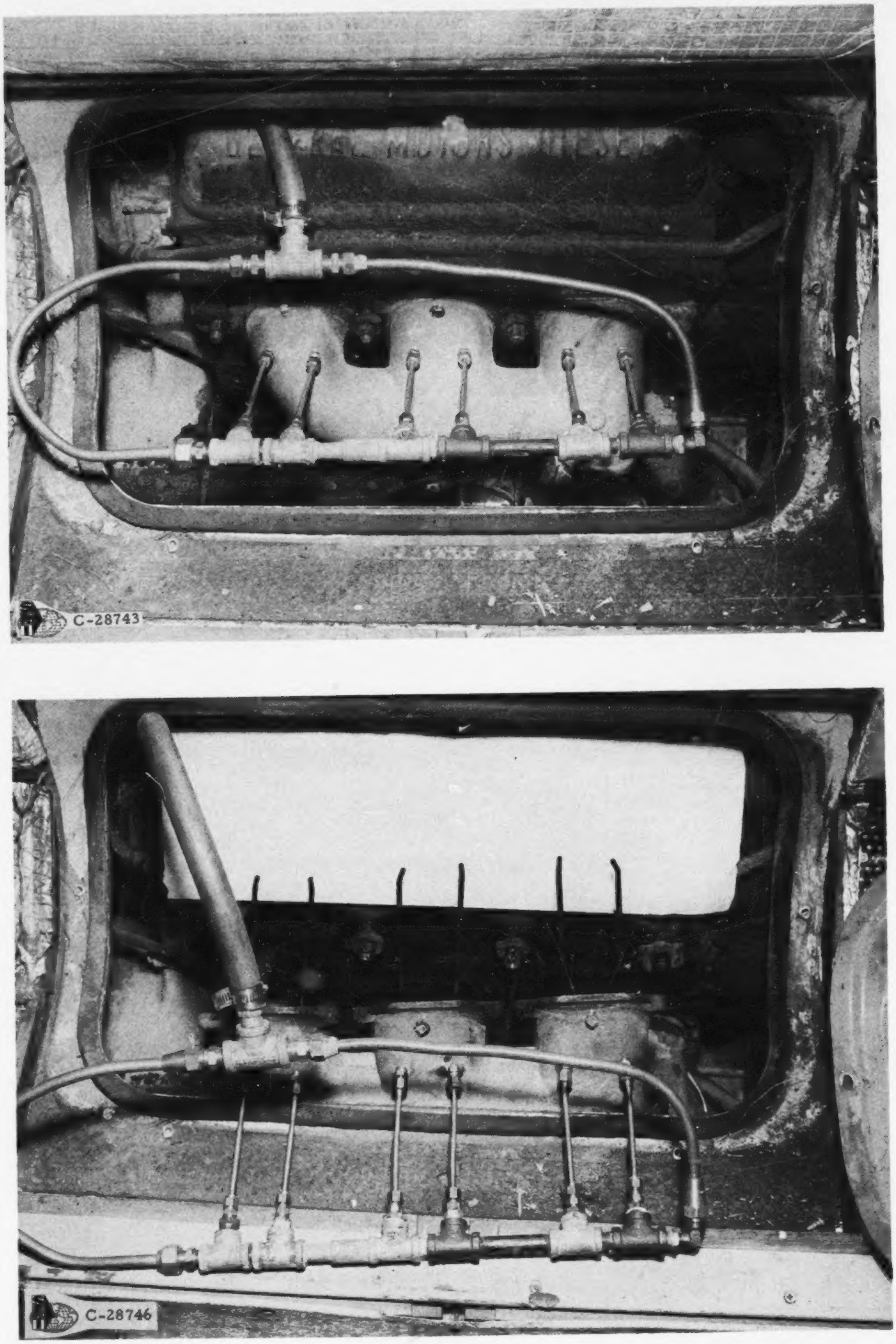
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FIGURE 47. FRESH AIR INJECTED IN TWO-STROKE ENGINE AS EXHAUST EXITS VALVES(93)

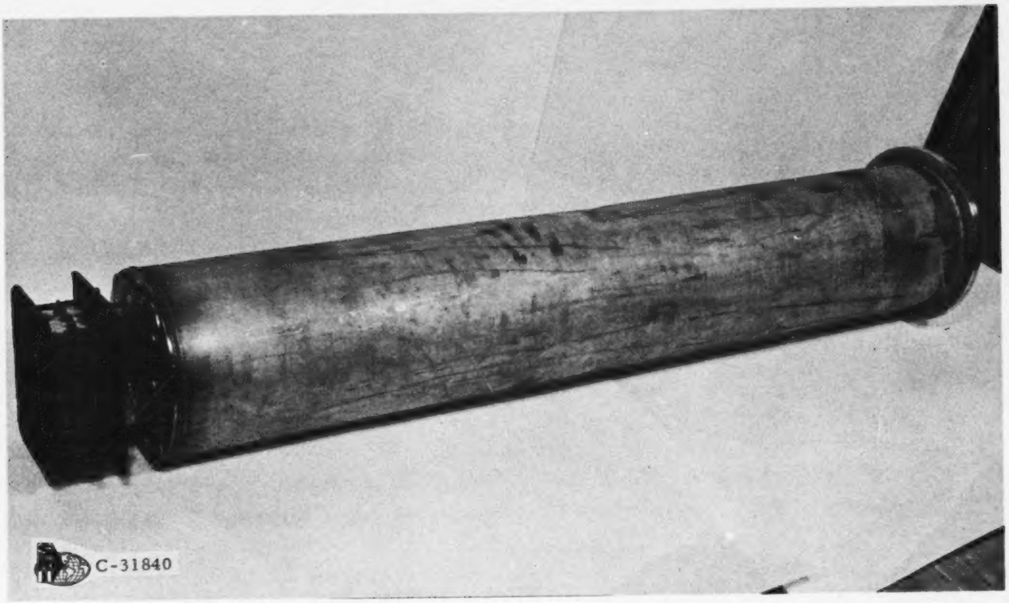


FIGURE 48. EXTERIOR OF ELECTROSTATIC PRECIPITATOR FOR DIESEL SMOKE REMOVAL(115)

(Exhaust Flow Is Left to Right)

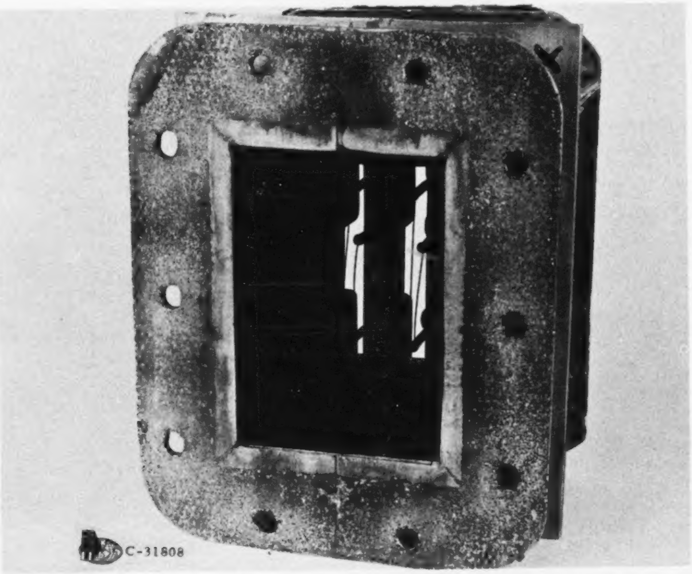


FIGURE 49. GAS DISCHARGE SIDE OF IONIZER SECTION OF ELECTROSTATIC PRECIPITATOR SHOWING CARBON DEPOSITS AFTER 46 MINUTES OF OPERATION ON A STATIONARY DIESEL ENGINE(115)

IV. GUIDELINES FOR MINIMUM ODOR

As mentioned in the "Guide," guidelines for minimum diesel odor are substantially more difficult to generalize and document than those for smoke. This is because less is known about causes and factors influencing diesel odor. Though the same "effects" categories are used as included in the smoke guidelines section, the text is briefer, reflecting the level of current knowledge.

A. Effect of Engine Size and Application on Odor

Guidelines for the selection of diesel engines for reduced odor are difficult to generalize, document, or recommend since it is only possible to discuss these in terms of engine types. The selection involves the entire vehicle design and goes beyond engine type or size. Broadly speaking, incomplete combustion brought about by inadequate air-fuel ratios, inadequate fuel injection, inadequate time for the burning process, insufficient temperatures to promote complete combustion, incorrect fuel, improper speed, etc., are all factors which may influence the odor from engines. Experience indicates that engines operated in highway type applications in vehicles equipped with vertical stacks result in less noticeable odor than diesel-powered vehicles equipped with horizontal exhaust pipes. Also, the same engine has been shown to produce less odor when operated under highway type conditions than in the city type stop-and-go service. Although not all the reasons for this are understood, engine temperature and engine speed may have a bearing. Figure 50, Reference 93, indicates the odor intensity characteristics of diesel buses powered by these types of diesel engines. This is an example of the need to not only consider engine type but application as some of these engines exhibit different odor levels when operated under intercity truck conditions.

Engine size, i.e., displacement and power output, does not influence exhaust odor as much as it affects smoke. The effect of load and speed is demonstrated by the fact that odor intensity generally increases toward the no-load condition for most operating speeds as indicated in Figure 51.(223) At low or high idle (zero power output), some engines will produce a noticeable amount of odor(90, 92, 93, 95) but no visible smoke.(92, 95) Minimum odor is shown to occur at part (one-half) load in Figure 51.

Very limited data indicate that odor levels from four-stroke turbocharged engines are not generally different than those from the naturally aspirated four-stroke engines, according to Figure 52, except sometimes during acceleration.(92, 115) Turbocharging during constant speed cruise can effect in some engines a slight reduction in odor, although this has not been shown to be a gross effect.(92, 115) One item which does have a gross effect is the location and placement of the exhaust pipe. The quantity or

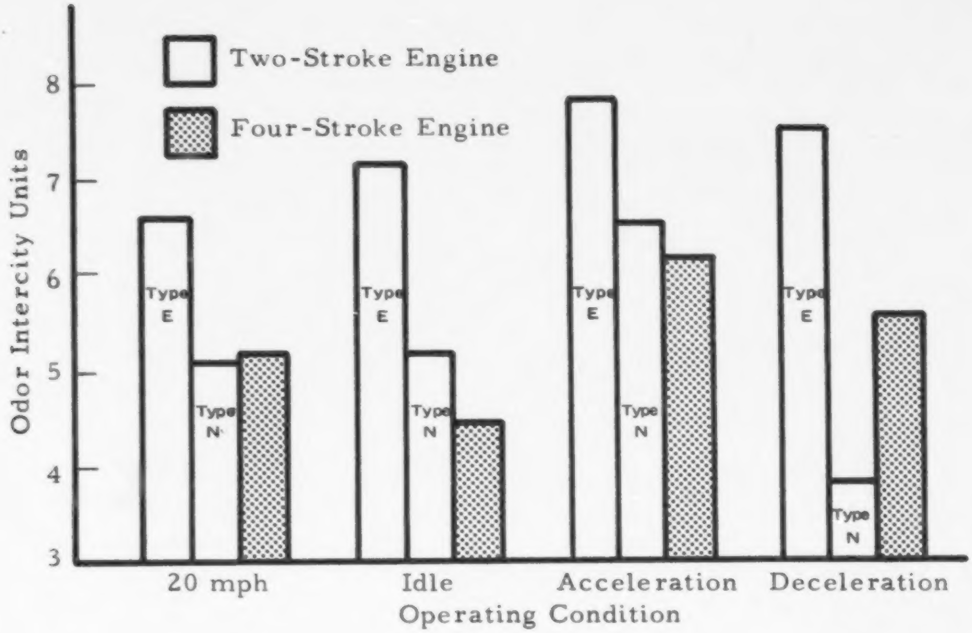


FIGURE 50. ODOR INTENSITY CHARACTERISTICS OF DIESEL BUSES WITH THREE DIFFERENT TYPES OF POWER PLANTS(93)

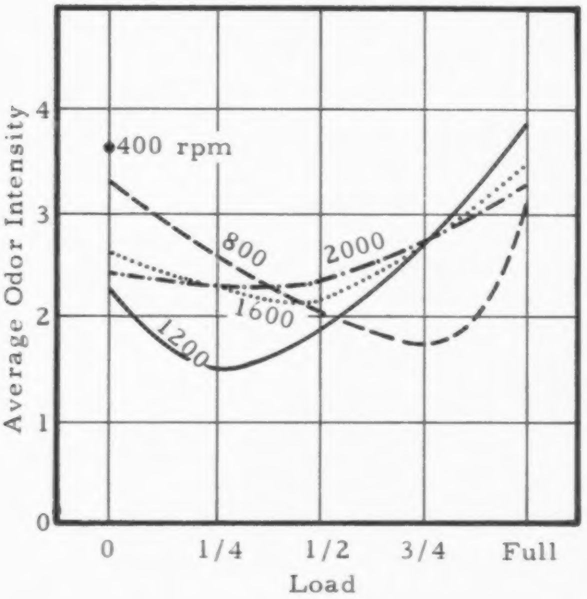


FIGURE 51. EFFECT OF ENGINE SPEED AND LOAD ON ODOR(223)

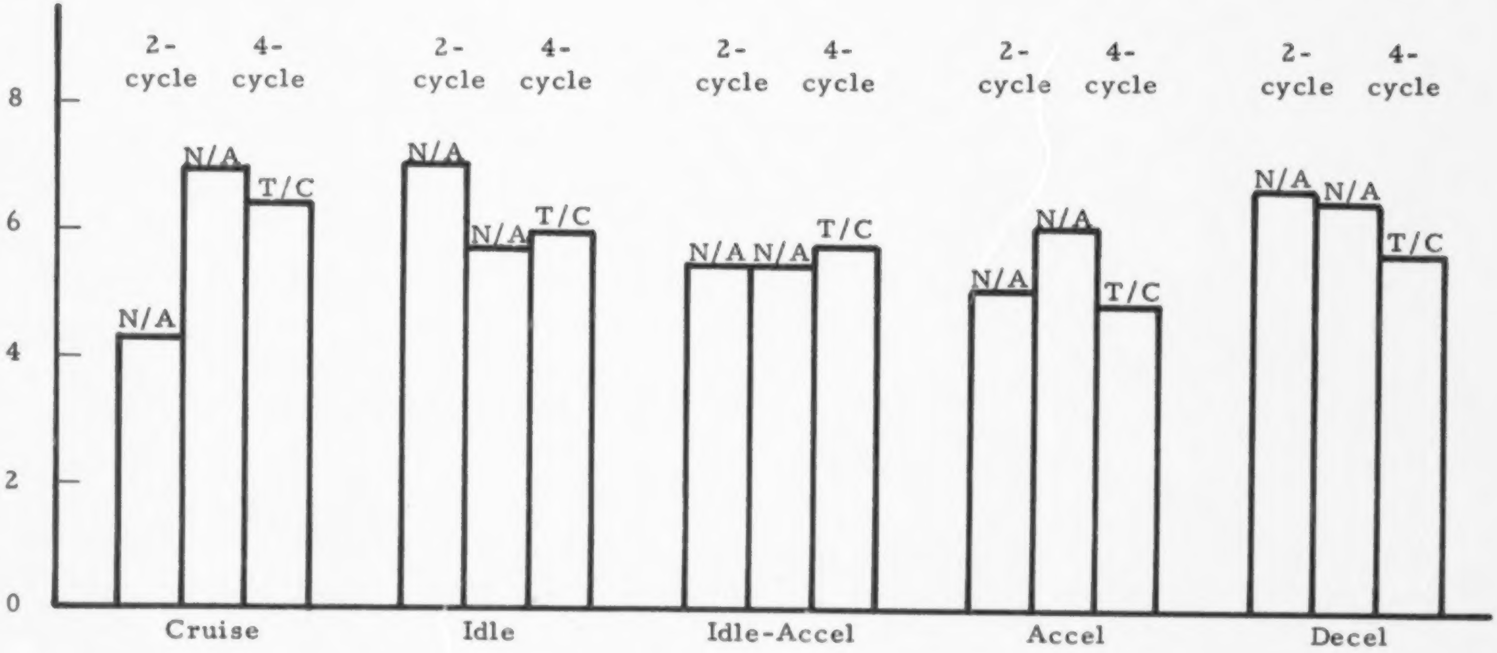


FIGURE 52. ODOR LEVELS FROM TWO- AND FOUR-STROKE NATURALLY ASPIRATED AND TURBOCHARGED DIESELS(92, 115) (700:1 DILUTION)

quality of odor is not reduced but is dispersed and sometimes less noticeable by the public. For this reason, vertical stack arrangements have been found to result in less perceptable odor than low to the ground or horizontal type discharges.(95)

B. Effect of Engine Derating on Odor

Both field and laboratory experience indicate little advantage in engine derating for the sole purpose of reducing odor.(92, 93, 95) Normally, the effects of a moderate amount of derating, in a well-maintained engine, are difficult to perceive, as is shown in Figure 53.(93) Speed and power variations within the operating range of the engine seem to have only a slight and inconsistent effect on odor from most engines and vehicles tested to date.(92, 95, 113, 114, 115, 119, etc.) It appears that an engine may have a significant influence on the odor produced, and, regardless of the level of maintenance, type of fuel, and even the engine rating, the odor level may tend to persist.

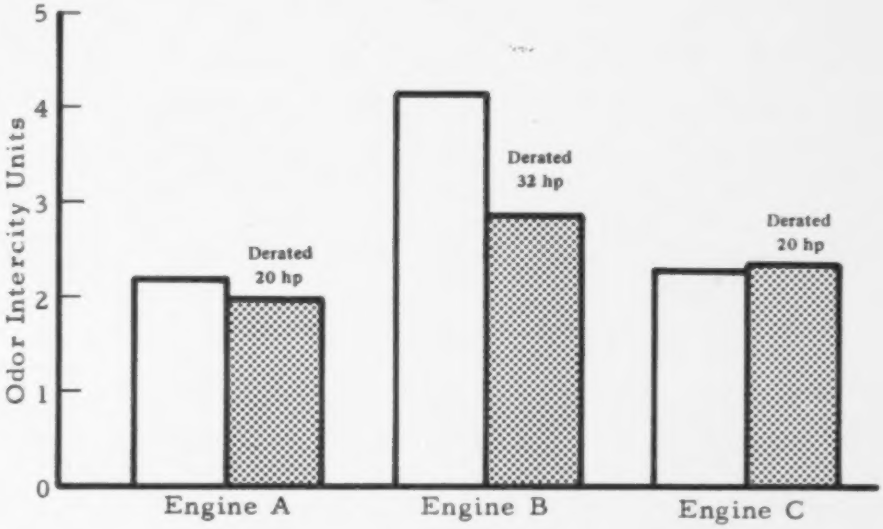


FIGURE 53. EFFECTS OF ENGINE DERATING ON EXHAUST ODOR INTENSITY FOR THREE DIESEL TRACTORS-- MAXIMUM POWER AT 2100 RPM(93)

C. Fuel System Maintenance Affects Odor

Engine maintenance can have an effect on odor. Depending on the engine type, fuel injection characteristics can have as much effect on odor as they do on smoke. In a previous section, it was mentioned that combustion efficiency was more important than the quantity of fuel injected for controlling odor. In most instances, improvements in combustion reduce both smoke and odor. For example, the difference in the smoke output between the "E" series and "N" series engines has already been demonstrated. The difference in the odor levels between the two engines types has been determined by two independent studies in Figure 54(92, 224) and Figure 55.(94)

Most manufacturers of automotive engines have very active development programs aimed at reducing exhaust smoke, odor, and other emissions. From time to time, improved products will become available which often can and should be incorporated into older engines. As an example, it has been reported by the manufacturer(3) and confirmed by others(3, 92, 93, 115, 136) that replacing the crown type "S" fuel injector used in older Detroit Diesel 71 series engines with needle type "N" injectors will reduce smoke, odor, and other emissions. Recently, an improved version of the "N"-type injector has been put into production; it is currently furnished in new engines and also

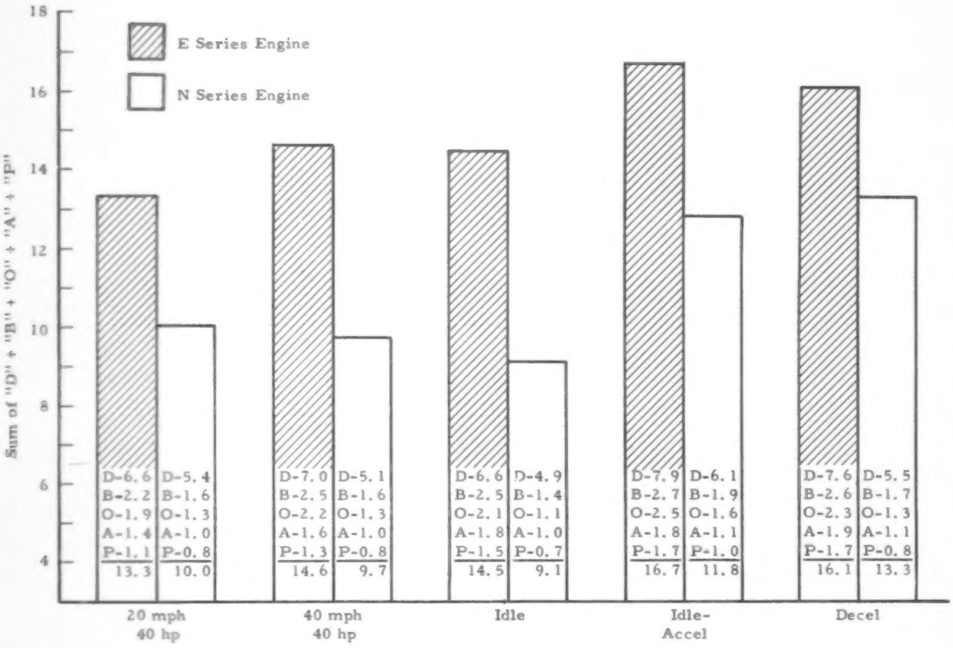


FIGURE 54. COMPARISON OF ODOR FROM 10 E- AND 10 N-TYPE DETROIT DIESEL 6V-71 POWERED MUNICIPAL BUSES(92, 224)

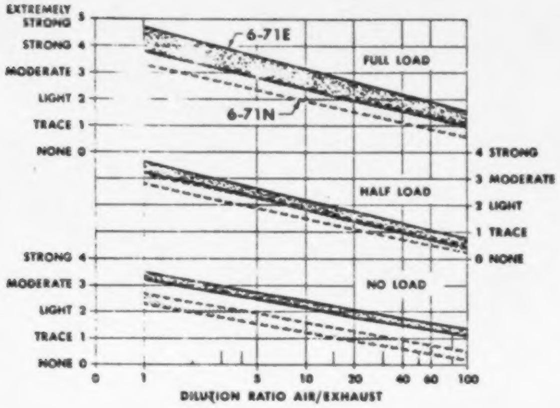


FIGURE 55. ODOR LEVELS FROM E AND N SERIES TWO-STROKE ENGINES(94)

replaces the "N" as described in the previous service bulletin, Figure 33. It is possible to achieve almost the same improvement in odor by replacing the "S" injector used in many of the existing engines with the "N" injector at a nominal cost. The reduction in odor possible with the "N" relative to in-service "S" injectors in the same E engine is shown in Figure 56.(115) Thus, substantial reductions in both smoke and odor from this engine can be achieved during periodic maintenance by simply changing injector type.

An injector with a deteriorated spray pattern or cutoff may be the cause of a significant level of odor. If fuel is injected into the combustion chamber after the normal cutoff point, it may be only partially burned. For example, during deceleration of two-stroke engines with "S" injectors, a fairly pungent odor may be observed due to fuel seepage.(94) The reason for this may be noticed in the design of the injectors, illustrated in Figure 57.(136) By moving the point of fuel cutoff nearer the spray tip with a needle valve and seat, less fuel is available to leak into the combustion chamber. Obviously, other types of engines can also produce odor because of inadequate injector seal due to wear, deposits, or adjustment.

The effect of late injection on odor has yet to be investigated, but it is not expected to be significant. Low oil, metal, and water temperatures contribute greatly to the odor potential of any diesel engine. It is common experience that diesels tend to have higher odor levels in the winter than in the summer, or in cold climates relative to warm climates.(3, 67) Too much engine cooling, either by the water jacket or from within via the oil can increase odor. The proper maintenance and use of high temperature thermostats, thermostatically controlled shutters, or variable speed, thermostatically controlled fans are all techniques by which engine temperatures may be maintained at an optimum level. The use of maximum engine temperature,

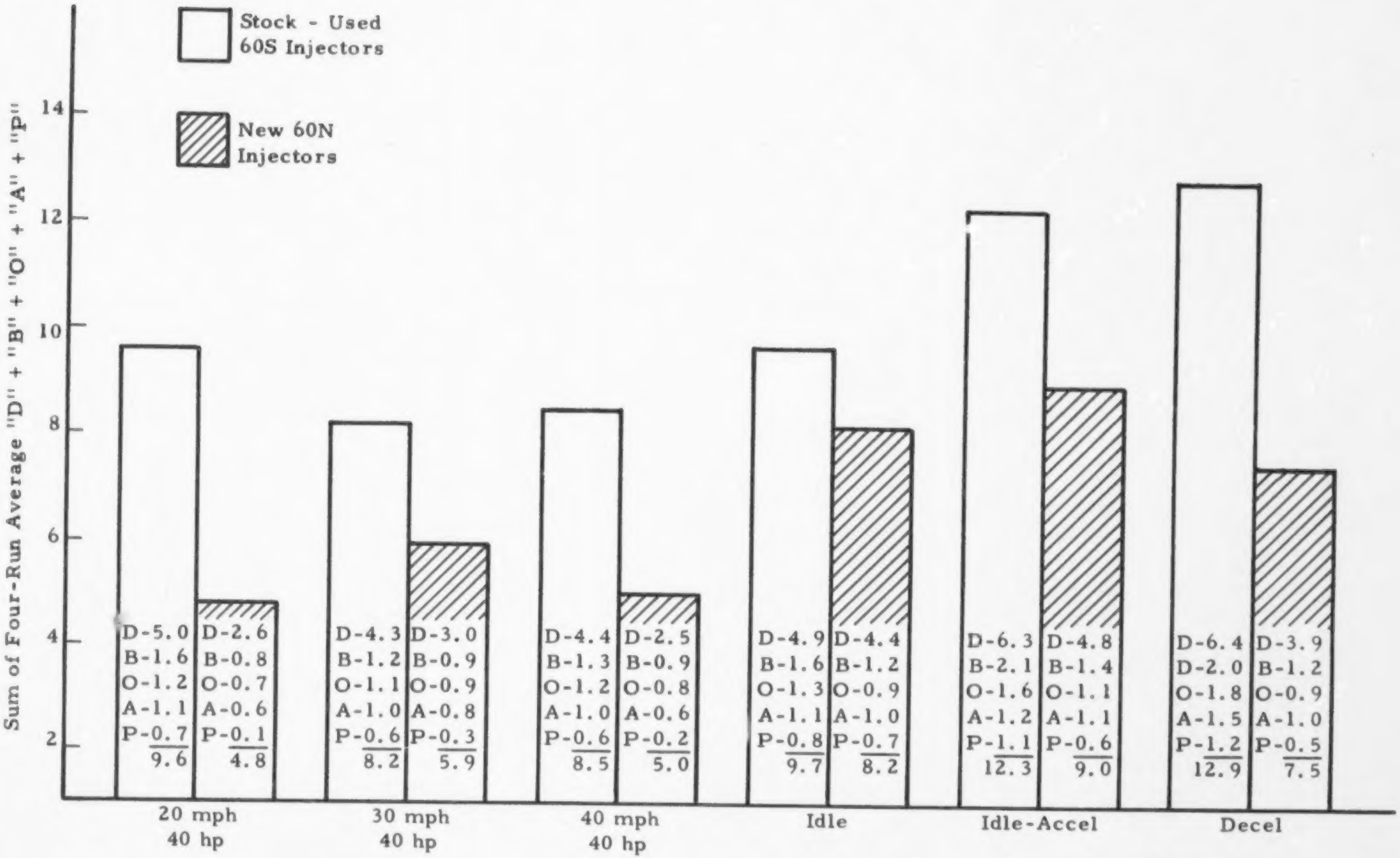


FIGURE 56. COMPARISON OF ODOR RATINGS FROM 6V-71 E POWERED BUS 681 EQUIPPED WITH USED "S" AND NEW "N" TYPE INJECTORS(115)

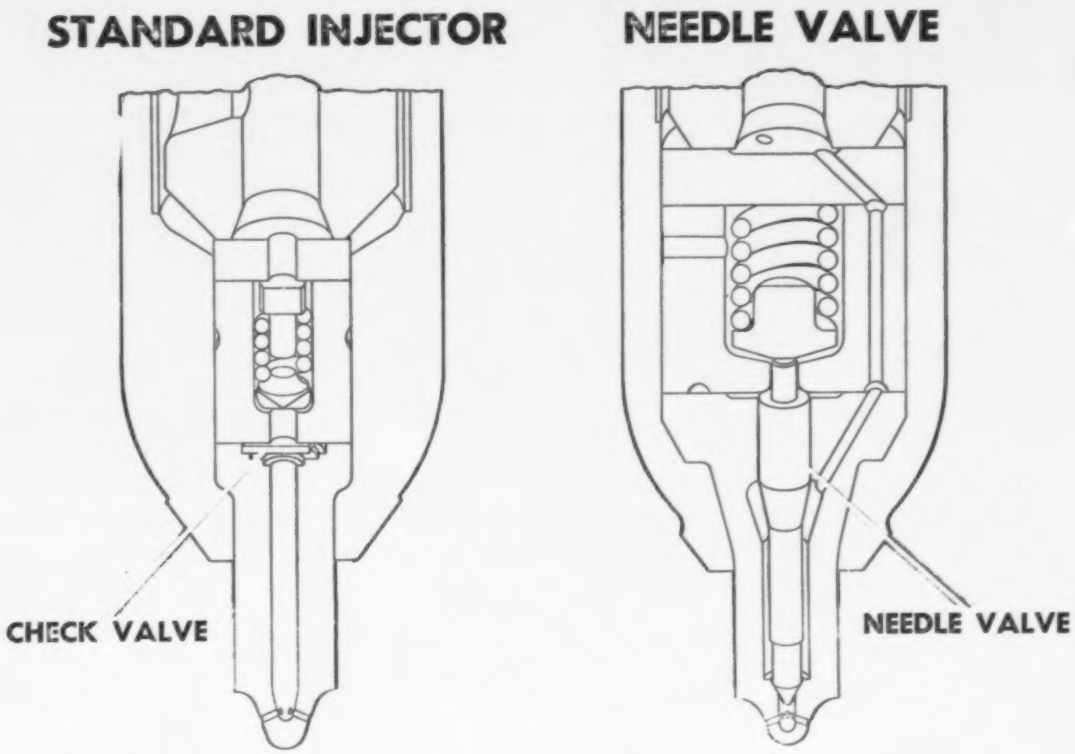


FIGURE 57. "S" AND "N" TYPE UNIT INJECTORS(136)

especially under winter conditions, is recommended. This is normally not a problem in line-haul operation but is more pronounced in intracity stop-and-go service, especially with extended periods of idle or low power output.

D. Induction and Exhaust System Maintenance Affects Odor

The induction system has a significant effect on odor in some applications and engine types. A seriously restricted inlet will result in exhaust products of a highly malodorous nature. Limited investigations have shown that blockage of the air cleaner on certain naturally aspirated engines, or impaired performance and delivery characteristics of the scavenge blower on certain two-stroke engines, can not only increase the overall odor intensity, but can make the odor more disagreeable. This was first noted, though not reported, during the efforts of References 92, 95, and, more recently, reported in Reference 119. The partial restriction imposed by certain turbochargers during idle and acceleration from idle likewise may result in transient odor levels that may be different from that normally produced under cruise type operation at speed and load although there is no known data regarding this effect. With some engines, air temperature can be important since some engines tend to produce more objectionable odors during cold startup or when operating in cold ambient conditions such that incomplete combustion occurs.(67)

All diesel engines use valves either to exhaust the products of combustion or to permit entrance and exit of air and exhaust gases into the combustion chamber. Inlet and exhaust "tune" is important to eliminate potentially destructive and performance robbing pulsations which influence the ability of an engine to breathe and obtain a full charge of air for each combustion stroke. Arbitrarily changing or replacing portions of these systems with non-standard or non-stock items should be avoided. The acoustic phenomena within the inlet and the exhaust system are generally not sufficiently understood to permit field alteration without advice of the vehicle manufacturer.

Many fleet maintenance departments have established internal fleet maintenance procedures, PM schedules(225), and service policies based on the manufacturers' recommendations and service manuals(156-159) as well as their own direct experience. The result is an individualized approach tailored closely to the fleet application and need.(140) Service bulletins concerning parts and procedural changes are published by the manufacturer and should be incorporated into the fleet maintenance procedures. Followup with the mechanics is usually effective in keeping the odor and smoke as low as possible with engine maintenance. It is recommended that, where smoke and odor control are not emphasized, a continuing program of information, education, and training be considered that advocates the need for clean, clear exhaust. An incentive program or other recognition has, when carefully applied, demonstrated management's concern for these emissions and resulted in better odor and smoke control.(3)

E. Effect of Driver Technique on Odor

Just as the driver can influence the amount of smoke from his vehicle, so is he able to reduce odor under certain conditions. Road adjustment of the engine fueling system to increase power not only increases the smoke output, but can increase odor as well. Figure 53(93) shows this effect on tractors powered by three different types of engines. In one instance, the increase in power did increase the perceived odor. Therefore, there is a double reason for not making such adjustments. To minimize odor, it is normally helpful to keep the engine speed up, and this is particularly true for two-stroke engines. This effect is shown in Figure 58 for one two-stroke engine and was noted at all power output or fueling rates(119) investigated. The effect of engine speed on odor for most four-stroke engines is not as pronounced(226), although there is not as much data available as for two-stroke engines. Engine temperature is thought to be important because it affects combustion efficiency.

Another way the driver and only the driver can help to minimize odor is to minimize idle and light-load operation. Certain engine types, particularly during warmup or shortly after engine startup, will condense unburned fuel and products of combustion in the exhaust. A more intense odor may result, as shown in Figure 51, at 400 rpm. A good rule is to start the engine

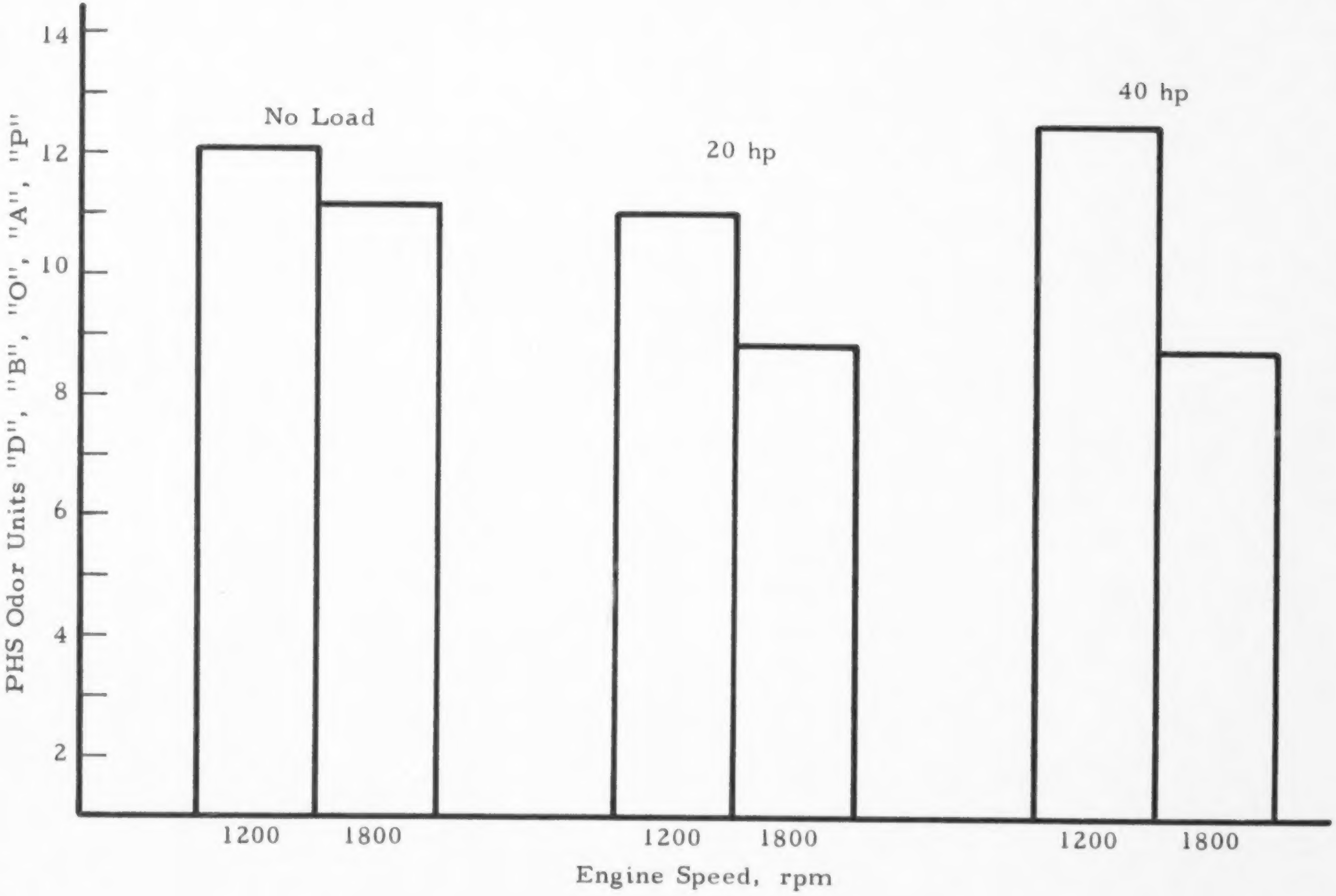


FIGURE 58. EFFECT OF ENGINE SPEED AND LOAD ON TWO-STROKE EXHAUST ODOR(119)

and get it under load as soon as practical. Idling the engine will generally do little to warm up the engine; it merely "loads up" the combustion chamber with unburned fuel which may dilute the lube oil.(125) Winter operation and stop-and-go city service are particularly acute in this regard. This operation usually includes substantial idle, either at the end of the run or intermittently at delivery points. It is recommended that the engine be shut off instead of being permitted to idle for extended periods. Some localities have approved regulations regarding engine idling practices. For example, the city of New York has a rule in effect which limits the idle of vehicles to no longer than 3 min(34).

Driver training and education is important in an overall program to reduce vehicle odor and smoke. Most vehicle manufacturers publish handbooks describing recommended driving procedures and References 166 and 227 through 229 are excellent examples. Encouragement by management to adopt driver attitudes conducive to less smoke and odor is an effective way to implement a program to improve the appearance of a fleet and reduce complaints or citations. Driver awareness of his potential for reducing odor and smoke must become a natural habit and be continually in thought. The Post Office Department currently has a driver indoctrination and training course for new drivers(230) as do most fleets.(3) Although the courses are designed primarily for vehicle familiarization, inclusion of techniques for reduced odor and smoke emissions could prove beneficial. Driver training, to be really effective on odor and smoke, cannot be an on-again, off-again affair or end with a check ride; it must be consistent, simple, and continuous. In summation, there are a number of things the driver can do to reduce smoke and odor emissions. Unless management stresses to the driver the need for reducing them, however, legislation may be the only recourse.(231)

F. Effects of Fuel on Odor

Fuel may have a noticeable effect on exhaust odor from certain types of engines and vehicles. While odor is generally attributed to partially oxygenated hydrocarbons, the specific compounds or even groups of compounds have not been identified. Studies of fuels with widely different properties and impurities have not pinpointed specific cause-effect relationships.(29, 66, 72, 115)

Even though research is incomplete, it is speculated that the obvious fuel properties such as boiling range (volatility), gravity, viscosity, and ignition quality may influence odor. For example, a low viscosity fuel could seep out of the injector (dribble) and enter the combustion chamber during the non-power part of the cycle. This fuel might only be partially oxidized by residual heat in the combustion chamber and exhaust system resulting in a malodorous exhaust. Fuels with particularly low cetane number may ignite later than desired with less than complete combustion, resulting in odorous, partially burned fuel products.(90, 113, 187) Improved exhaust odor as a result of increased volatility and cetane number have been reported(182) although others(173) found only marginal improvement, if any.

Trace impurities in the fuel may be of even greater importance to exhaust malodors than the usual properties. As an example, sulfur compounds, which are almost always present in diesel fuel, form various oxides of sulfur or react with hydrogen to form small amounts of hydrogen sulfide (rotten eggs) or mercaptans. However, there appears to be no direct correlation between sulfur content and exhaust odor.(72) Other impurities including engine lube oil may form malodorous compounds, but, again, there is little available information to base concrete guidelines.

In general, engines are optimized to operate on either Number 1 or Number 2 fuel. Operation of an engine optimized for Number 1 fuel may result in a more intense odor when operated on Number 2 fuel. For example, a heavier, burnt-smoky and sometimes more acrid odor has been noted from a municipal bus engine operating on Number 2 fuel. However, less of the usual kerosene type fuel odor was present. One investigation(173) reported a tendency for kerosene to impart more noticeable odor at 50 to 75 percent of full load at 1200 rpm. In other investigations, small odor differences were found irrespective of speed and load or amount of fuel injected.(92, 95)

Additives are available for controlling odor and may be classed as maskants (cover odor with another odor) or counteractants (react with odor to form another odor or destroy odor). Some operators have found that the use of odor additives, principally the maskant type, has helped to reduce complaints.(173, 232-235) Although laboratory tests have not shown a reduction in odor level(29, 72, 92, 95, 173), it may be that through an active public information program, the modified odor is more acceptable. In addition to the cost, the major disadvantage of the maskant may be the creation of an odor that may be more unpleasant to some people than the original odor.(233) No engine difficulties or maintenance problems have been reported when using such additives.

Most diesel manufacturers have definite fuel recommendations for satisfactory engine operation.(227, 228, 236) In addition, marketers of diesel fuel are also very helpful in matching the fuel specification to the particular engine and job application. The advice of both engine manufacturer and the refiner should be obtained when determining fuel specifications for purchase, especially for abnormal types of climatic or duty cycle operation. Some engine manufacturers specifically warn against use of additional fuel additives other than those which they have approved. In some cases, the engine warranty may be jeopardized. As an example, the General Motors' policy is stated below:(237)

> "It has been and continues to be General Motors' policy to build motor vehicles that will operate satisfactorily on the commercial fuels and

> lubricants of good quality, regularly provided by the petroleum industry through retail outlets. It is accordingly contrary to the policy of General Motors to recommend the regular and continued use of supplementary additives in such fuels and lubricants.
>
> This policy should not be confused with the fact that certain supplementary additives may effectively and economically solve specific operating problems which occasionally arise in some vehicles. In such instances, supplementary additives may be developed on the basis of suitable tests to remedy such problems without otherwise causing harm to vehicles. These selected products are then given official GM part numbers and made available for use in appropriate service applications.
>
> While General Motors Corporation assumes responsibility for the additives selected by it to remedy specific operating problems, it cannot, of course, accept responsibility for the many other additives which are constantly being marketed."

Recently, NAPCA proposed a set of requirements(238) that additive manufacturers and fuel refiners would have to meet regarding registration of additives used in motor gasoline. In addition to chemical formula, if known, and concentration, data on the effects of the additive on other exhaust emissions, toxicity, etc., would be requested. It seems only a matter of time before diesel fuel additives will be covered in a similar action. References 239-244 describe some of the various smoke and odor additives currently on the market.

G. Effect of Control Devices on Odor

Control devices for diesel odor include catalytic mufflers and many of the other methods proposed to reduce smoke.(35, 85, 142, 147, 153, 161, 189, 245-258) Some catalytic mufflers of the precious metal type are shown in Figures 59 through 62. A few have been effective in reducing odor although other types of catalysts have had limited success in some applications. Street and highway application of even the best catalytic muffler is difficult because of the dependence of the catalyst and reaction rates on available heat energy in the exhaust.(3, 250) In some applications, such as stop-and-go city delivery involving extended idle periods, catalytic mufflers are only partially helpful in reducing odor.(3, 92, 259) This approach has found its best application with higher temperature exhaust in which the exhaust flow is nearly constant, such as a stationary engine or line haul vehicle. Most fleet operators feel the initial cost of equipment and installation (as much as $500 on some vehicles)(248) and the cost to operate and maintain do not justify use of catalytic mufflers except when extended operation in confined, unventilated, areas is a must. Even then the reduction in exhaust odor and irritants may be less than 50 percent.(92, 93, 147)

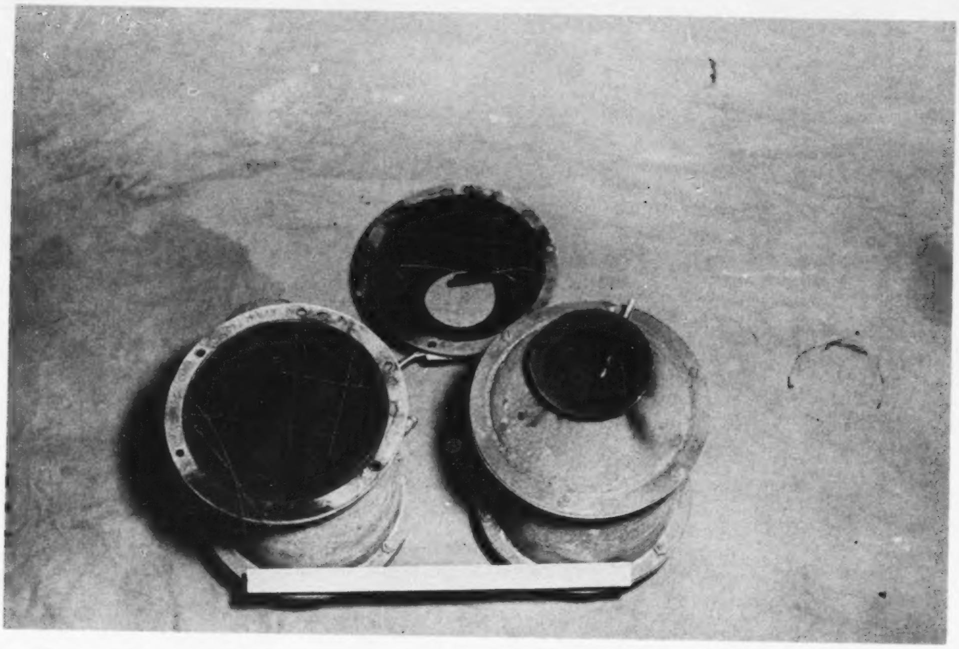


FIGURE 59. PRECIOUS METAL HONEYCOMB DIESEL EXHAUST CATALYST-DISASSEMBLED(224)

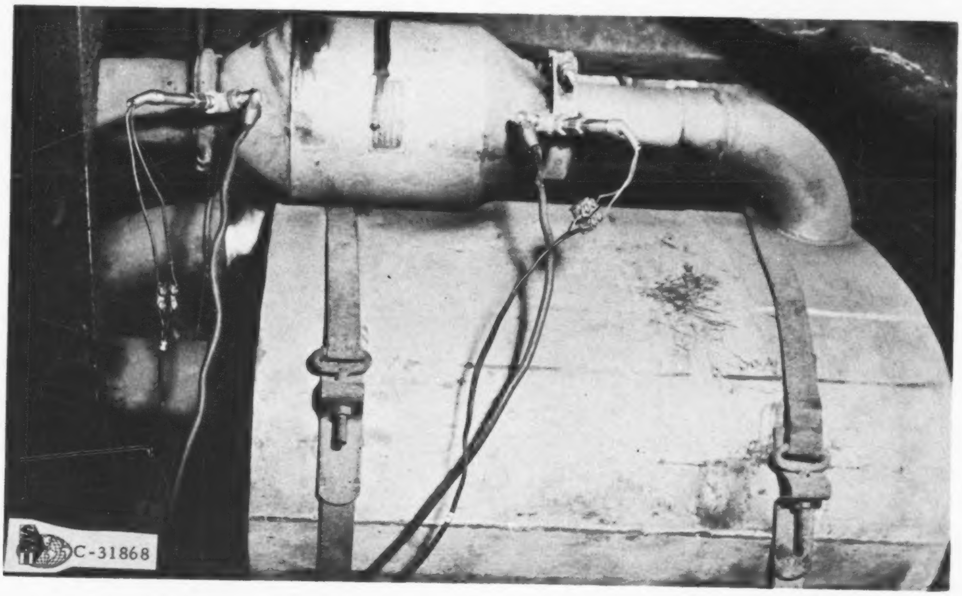
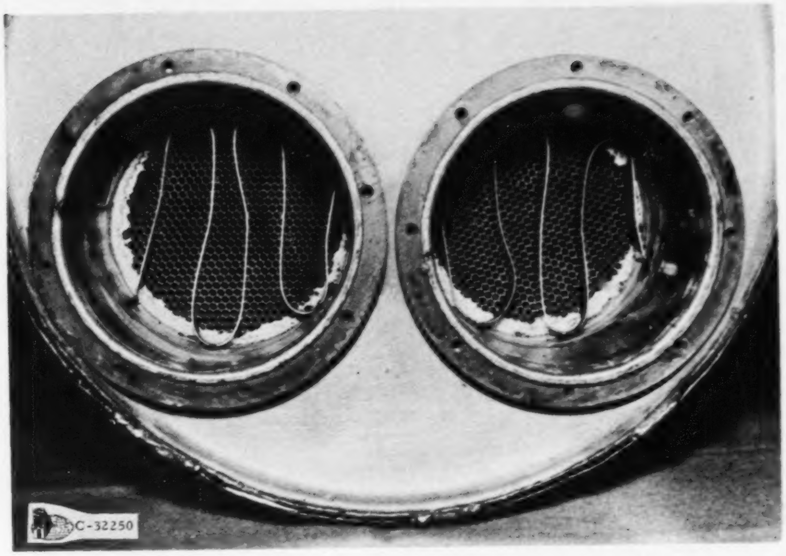


FIGURE 60. PRECIOUS METAL CATALYTIC MUFFLER UNDER TEST(224)



Before Test 0 Miles 0 Weeks

After Test 5,420 Miles 8 Weeks

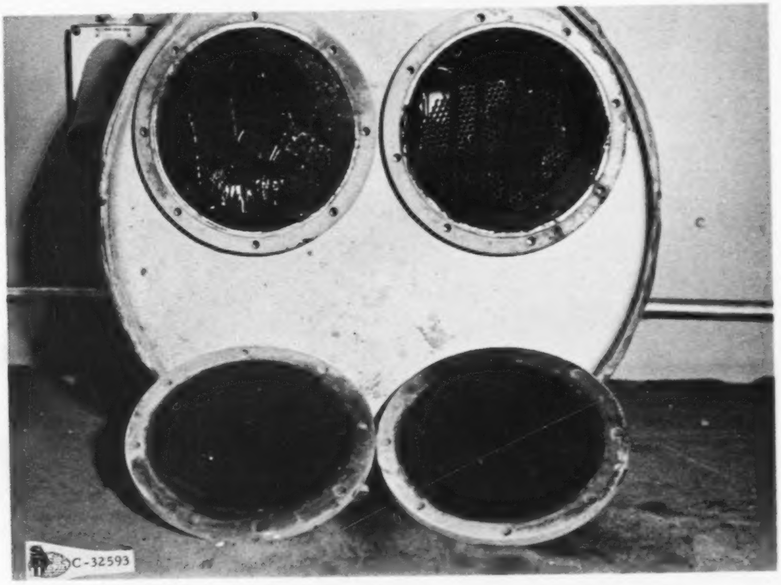


FIGURE 61. BEFORE AND AFTER TEST OF HONEYCOMB SUBSTRATE-PRECIOUS METAL CATALYTIC MUFFLER(224)

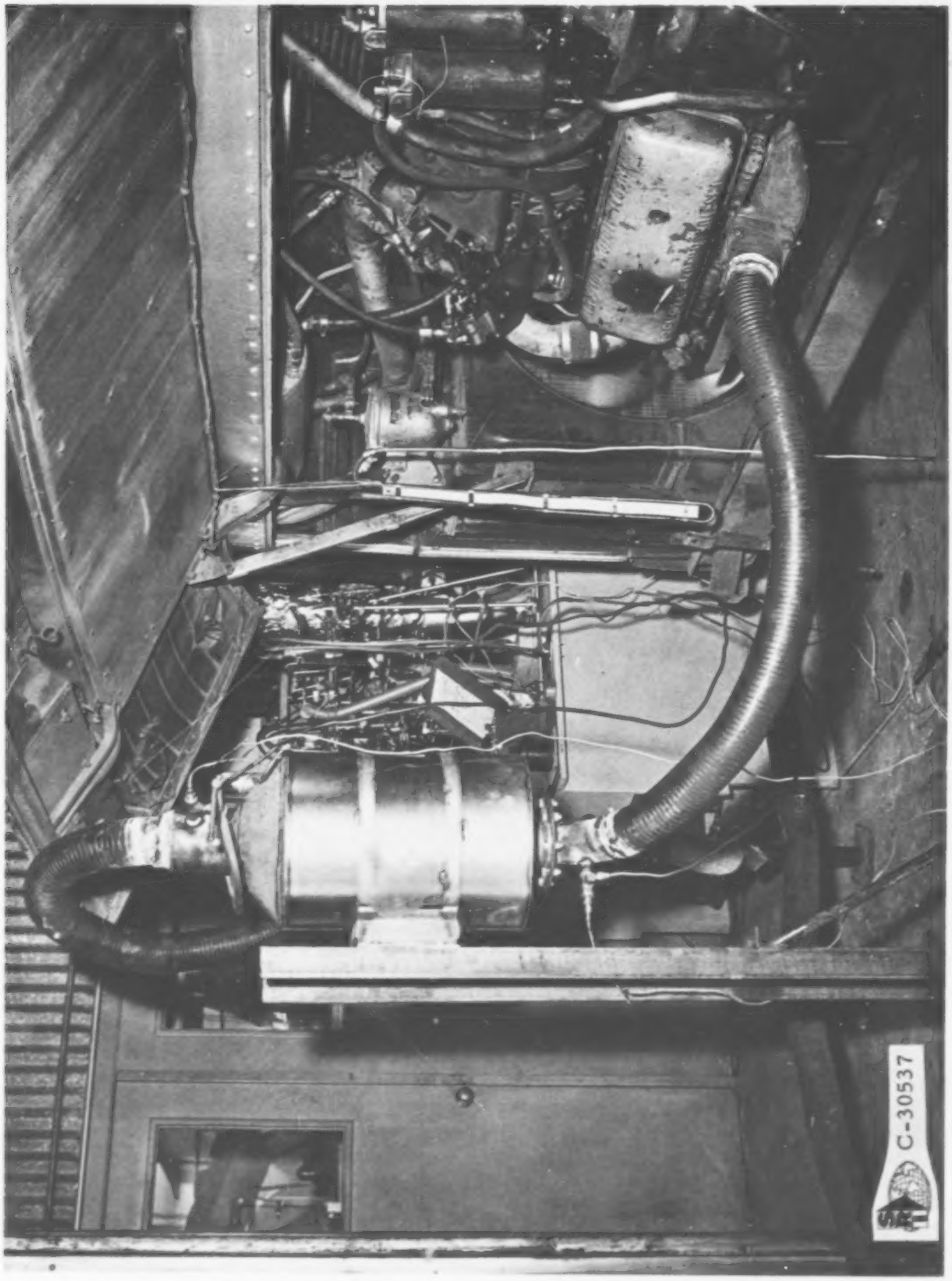
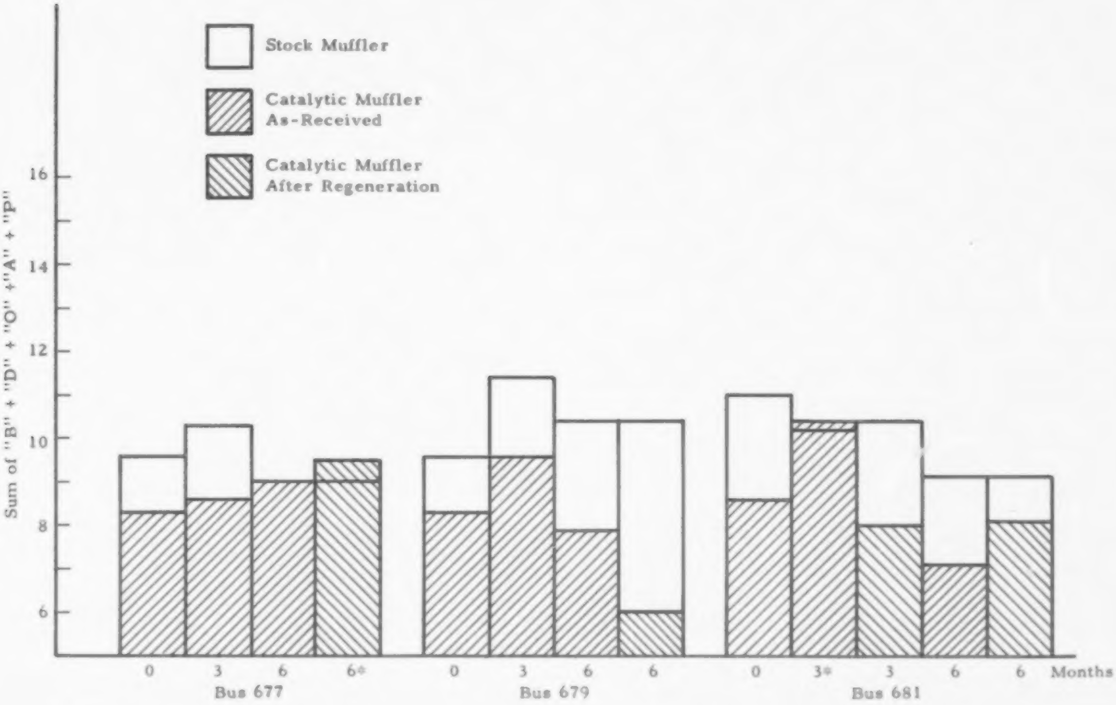


FIGURE 62. PRECIOUS CATALYTIC METAL MUFFLER

Typical reductions are shown in Figure 63 for the 30-mph cruise during a recent 3-bus fleet test using the catalytic device shown in Figure 62. Some designs require periodic or even continuous burnoff of contaminants to renew the catalyst surface and maintain performance.(248, 251) This means additional equipment and operating cost and, in some applications, could be a safety factor. Further research and development will be necessary to obtain the full potential of this method as well as make it usable on a greater variety of motor vehicles.(224)



*Catalytic greater than stock.

FIGURE 63. PERFORMANCE OF PRECIOUS METAL CATALYTIC MUFFLERS ON EXHAUST ODOR(224) 30 MPH - 40-HP CRUISE

As mentioned earlier, placement of stacks and direction of vehicle exhaust can have an important effect on the odor noticed by the pedestrian or motorist.(92, 93) More than merely diluting the exhaust, the odorous exhaust gases can be directed away from the observer. Although it does not destroy or reduce the total amount of odor, the nuisance effect can be reduced. The increase in atmospheric dispersion can be three to ten times by using a vertically directed stack terminating 10 to 12 ft above the road instead of a horizontal discharge at 1 to 2 ft above the road as shown in Figures 15 and 16. To reduce the noticeability of odor, vertical stacks are recommended with termination as high as practical above the road.

Next to stack placement, fuel injection seems to have the most important bearing on odor. It is expected that this could be one of the best ways in the future to gain positive, consistent reductions in both odor and smoke. As an example, new, improved fuel injectors reduced odor and smoke by about one-third from several low compression version two-stroke engines(3, 92, 93, 95), and can be accomplished at a nominal cost per injector.

Other control devices such as afterburners and wet scrubbers have been proposed.(247) Direct flame incineration, though successful in some stationary applications for control of odor, has not been satisfactorily applied to the diesel. Variations in exhaust flow and the variety of engines and applications are seen as disadvantages along with probable cost and possible safety aspects. Wet scrubbers have been proposed but are even more difficult due to the weight and space needed to handle the large quantities of high temperature exhaust and not penalize engine exhaust system back pressure.

One helpful device that is often overlooked as an aid for controlling both smoke and odor is the tachograph which is currently a Post Office Department requirement on all diesel trucks. By checking driver performance (rate of acceleration, idle time, etc.), the tachograph could be a unique critiquing device provided it were used constructively as a driver educational tool.

Promulgation of Federal standards for diesel odor will require improved means for measurement and expression, as well as feasible means to effect control. Efforts are under way by both industry and government to develop a better understanding of odor and its measurement.

V. SUMMARY

Odor and smoke from diesels basically are problems in public relations. This was aptly put in an editorial which appeared in Diesel Equipment Superintendent of September 1968(260), and is reprinted in its entirety as Figure 64. The basic theme of this project, to develop a "Guide," is contained in this editorial and it fairly well summarizes the basic features of the Guide which were:

(1) Air-fuel ratio has the greatest effect on smoke from the diesel engine and anything which tends to reduce this ratio either by excess fuel or insufficient air will lead to more smoke.

(2) Engine derating is the most popular method to obtain reduced smoke and is often a matter of procurement policy.

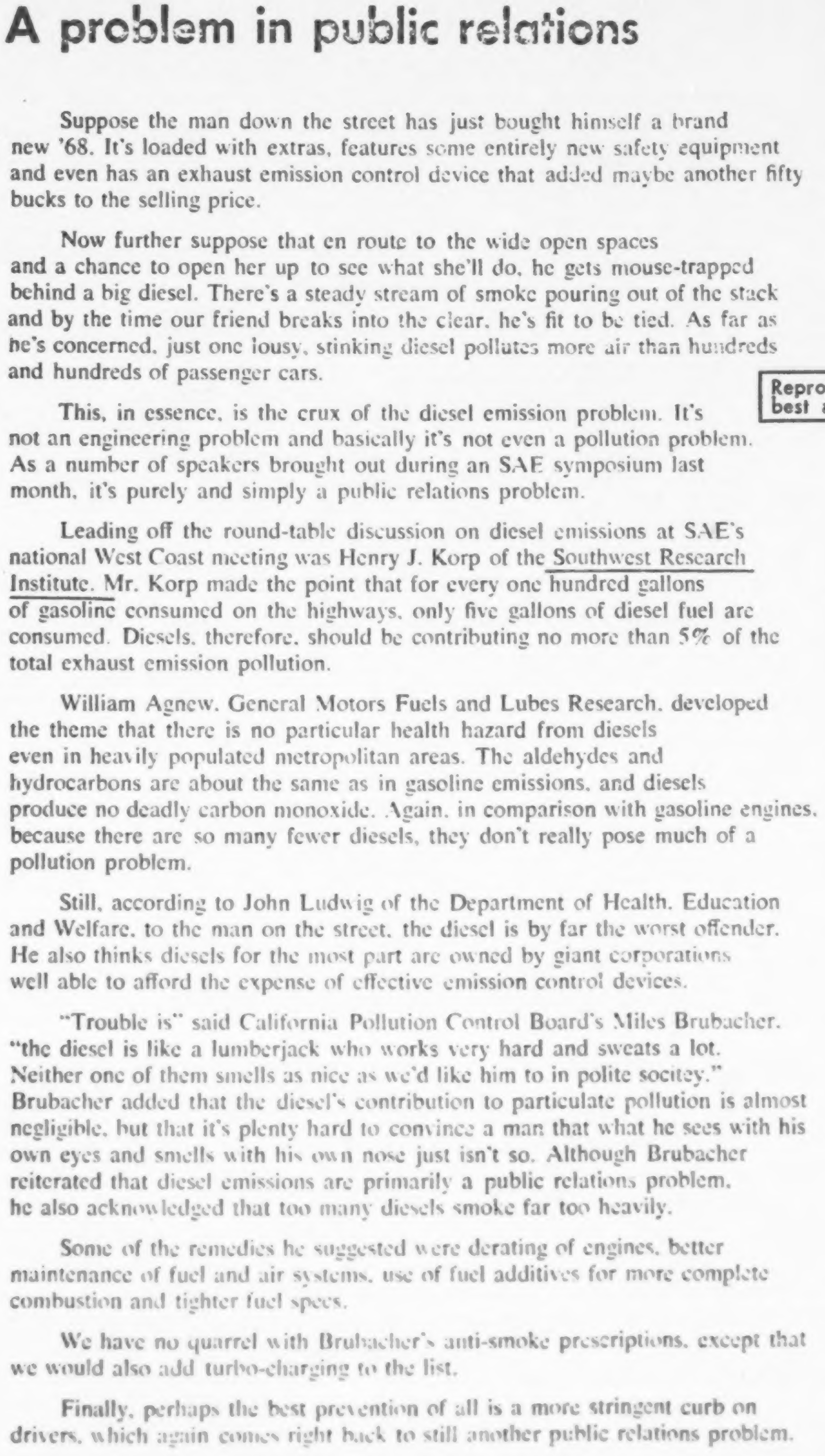
(3) Maintenance of vehicles and engines must include a continuing campaign against faulty fuel injectors, clogged air cleaners, and incorrect adjustment of injectors, etc.

(4) Turbocharging is a widely used method for minimizing visible smoke during operation at high elevations. Many new engines are procured with this feature though some manufacturers offer a kit to modify existing naturally aspirated engines.

(5) Odor and smoke can be reduced from certain two-cycle engines by the use of improved needle type unit injectors instead of the crown type injector. Use of the needle injector in the older E type engine is almost as effective on odor and smoke as the N-type engine and can be accomplished at a nominal cost per injector.

(6) The driver by his driving technique can substantially reduce odor and smoke. Less engine idle and underspeeding, "lugging," will reduce the odor from some engines. Lugging is also a major reason for noticeable smoke from certain engines. The use of a rear view mirror aimed at the exhaust outlet along with active and continuing driver education will aid in encouraging the driver to operate so as to produce less smoke and odor.

(7) The location and direction of the vehicle exhaust stack or pipe can make a significant difference in the noticeable and potentially objectionable aspects of smoke and odor. To reduce the noticeability of odor, a straight vertical stack, terminating as high above the ground as possible, is recommended. In some stop-and-go applications in public areas, a horizontal, low to the



A problem in public relations

Suppose the man down the street has just bought himself a brand new '68. It's loaded with extras, features some entirely new safety equipment and even has an exhaust emission control device that added maybe another fifty bucks to the selling price.

Now further suppose that en route to the wide open spaces and a chance to open her up to see what she'll do, he gets mouse-trapped behind a big diesel. There's a steady stream of smoke pouring out of the stack and by the time our friend breaks into the clear, he's fit to be tied. As far as he's concerned, just one lousy, stinking diesel pollutes more air than hundreds and hundreds of passenger cars.

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This, in essence, is the crux of the diesel emission problem. It's not an engineering problem and basically it's not even a pollution problem. As a number of speakers brought out during an SAE symposium last month, it's purely and simply a public relations problem.

Leading off the round-table discussion on diesel emissions at SAE's national West Coast meeting was Henry J. Korp of the Southwest Research Institute. Mr. Korp made the point that for every one hundred gallons of gasoline consumed on the highways, only five gallons of diesel fuel are consumed. Diesels, therefore, should be contributing no more than 5% of the total exhaust emission pollution.

William Agnew, General Motors Fuels and Lubes Research, developed the theme that there is no particular health hazard from diesels even in heavily populated metropolitan areas. The aldehydes and hydrocarbons are about the same as in gasoline emissions, and diesels produce no deadly carbon monoxide. Again, in comparison with gasoline engines, because there are so many fewer diesels, they don't really pose much of a pollution problem.

Still, according to John Ludwig of the Department of Health, Education and Welfare, to the man on the street, the diesel is by far the worst offender. He also thinks diesels for the most part are owned by giant corporations well able to afford the expense of effective emission control devices.

"Trouble is" said California Pollution Control Board's Miles Brubacher, "the diesel is like a lumberjack who works very hard and sweats a lot. Neither one of them smells as nice as we'd like him to in polite socitey." Brubacher added that the diesel's contribution to particulate pollution is almost negligible, but that it's plenty hard to convince a man that what he sees with his own eyes and smells with his own nose just isn't so. Although Brubacher reiterated that diesel emissions are primarily a public relations problem, he also acknowledged that too many diesels smoke far too heavily.

Some of the remedies he suggested were derating of engines, better maintenance of fuel and air systems, use of fuel additives for more complete combustion and tighter fuel specs.

We have no quarrel with Brubacher's anti-smoke prescriptions, except that we would also add turbo-charging to the list.

Finally, perhaps the best prevention of all is a more stringent curb on drivers, which again comes right back to still another public relations problem.

FIGURE 64. EDITORIAL IN SEPTEMBER 1967 ISSUE OF DIESEL EQUIPMENT SUPERINTENDENT(260)

ground exhaust has been found superior when used with well-maintained equipment to reduce fallout of soot.

(8) The widely known fact that an engine operating on Number 1 diesel fuel instead of Number 2 results in less smoke may be attributed to physical factors of gravity, Btu content, and injection characteristics. When engines are operated to produce equivalent power output, the smoke output will be almost the same regardless of the commercial fuel used. In any event, the fuel should be selected to conform to the specifications around which the engine was designed.

(9) A number of fuel additives are being marketed for reduction in diesel odor and smoke. Some engine manufacturers specifically warn against use of unapproved fuel additives. In some cases, the engine warranty may be jeopardized.

In conclusion, a team effort by everyone involved in the application and purchase, operation, maintenance, and driving of diesel rigs cannot help but achieve the high goal of less odor and smoke. Continued research and development will make possible the realization of the inherently low odor and smoke potential of the automotive diesel.

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